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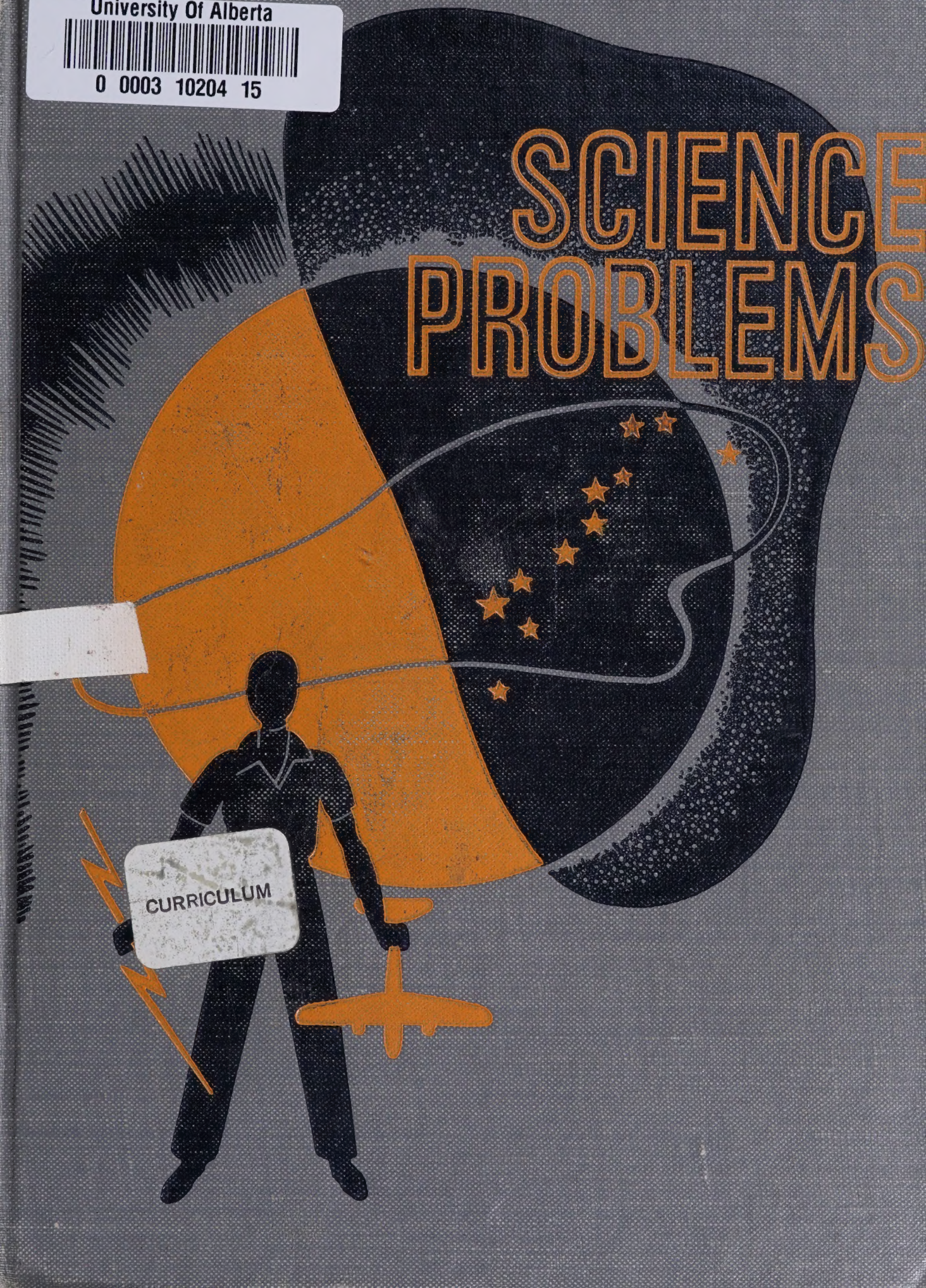

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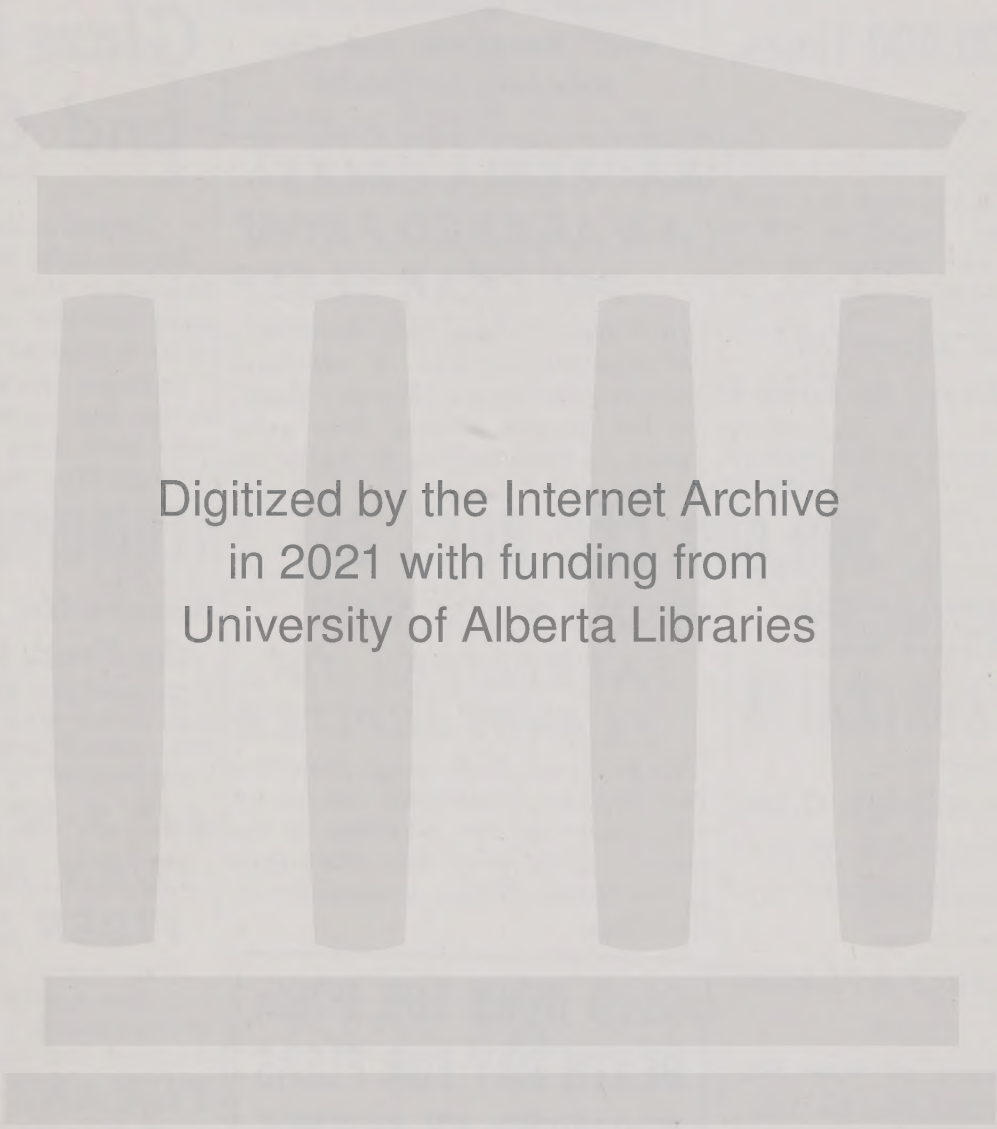
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INVISIBLE WORLD MADE VISIBLE BY NEW MICROSCOPE

German Device Magnifies Objects 100,000 Times.

BERLIN, Aug. 15.—(AP)—A hitherto invisible world is revealed in a super microscope that magnifies 100,000 times. It is a new instrument built by two young German scientists. Dr.

GIANT PLANT GROWN IN SYNTHETIC SOIL

Columbia Botanist Raises Tobacco in Pure Sand by Feeding It Chemicals

FINDS TONIC ESSENTIAL

Infinitesmal Quantities of Boric Acid, Manganese and Zinc Necessary for Health

EXPLORERS FIND ALASKA GLACIER 235 MILES LONG

Woman Makes Glass Invisible and Glareless

(Picture on Back Page.)

Schenectady, N. Y., Dec. 26.—(AP)—Discovery of a coating that makes glass invisible was announced today by Dr. Katharine B. Blodgett, scientist.

Ordinary thicknesses become clear as air, and reveal how much human eyes have been missing in looking through even the finest glass. Purest

Fond of Cod Liver Oil? Then Get Bossy to Take It

Beltsville, Md., Aug. 21.—(AP)—If you don't like carrots or cod liver oil, perhaps you can interest Bossy in eating them for you. I National Agriculture R said today that carrots

BACTERIA CELLS AWAKENED FROM 249 YEAR SLEEP

San Luis Obispo, Cal., April 16.—(AP)—Microscopic dots of life have been aroused from a 249 year "sleep" to the normal activity they abandoned in 1687, Dr. Ira B. Bartle reported tonight

300,000 CCC BOYS GET PNEUMONIA VACCINE

PARROT PROBLEM STIRS AUSTRALIA

Sudden Influx of Bright Green Birds Is Regarded With Alarm 'Down Under.'

VISITORS NEARLY A PLAGUE

Striking Example of How Nature's Scales Can Become Unbalanced, Says National Geographic Society.

Nature has toppled off her balance again; this time in Western Australia. Small green parrots

FINDS TWO NEW SATELLITES OF PLANET JUPITER

Washington, D. C., Aug. 29.—(AP)—The Carnegie institution announced today that two new satellites of the planet Jupiter have been discovered by its Mount Wilson observatory in California.

Beware the Fly! Cover the Food, City Is Warned

Beware the fly, the Greater Chicago Safety council warned yesterday. The council urged that all food be kept covered to prevent contamina-

GOOD NEWS FOR DOGS: DEATH RAY FOR FLEAS PRODUCED BY SCIENCE

New York, Dec. 28.—[Special.]—Science has developed a death ray machine for fleas. It is a simply constructed lamp that plugs into an electric outlet and casts an infra-red

ea within
The idea
og's hair,
move it

2 U. S. SCIENTISTS TURN MILK INTO FIBER LIKE WOOL

Washington, D. C., Aug. 15.—(AP)—A new American industry appeared in the making today when it was announced that two government scien-

TEXANS WARNED TO LEAVE PATH OF HURRICANE

Brownsville, Tex., Aug. 27.—(UP)—Men and women in the Rio Grande Valley put aside their usual tasks today and worked about their homes and farms, preparing for the gale that is expected to hit in this area tonight when a hurricane

eps inland from the Gulf of
xico.
he Weather Bureau warned that
center of the storm is expected
Mexican coast south of
slight deviation would

Heart Failure Explained By Deranged Cell Chemistry

STUDY of the chemistry that goes on in the individual muscle cells of the

have found, is a phosphocreatine compound. When this chemical is built up

BASIC STUDIES IN SCIENCE

Science Problems

For the Junior High School

BY WILBUR L. BEAUCHAMP · *The University of Chicago*

JOHN C. MAYFIELD · *The University High School · Chicago*

JOE YOUNG WEST · *Maryland State Teachers College · Towson*

BOOK 2

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Ackerman) 503, 505, 507, 536, 537, (photograph by Knoblock) 508; U. S. D. A., Bureau of Animal Industry, 525, 526, 527, 529, 541, 544; U. S. D. A., Bureau of Entomology and Plant Quarantine, 517, 520; U. S. D. A., Bureau of Plant Industry, 130; U. S. D. A., Soil Conservation Service, 128, 129; U. S. D. A., Weather Bureau, 49, 103, 104, 309, 321, 329, 330, 339 (bottom), 340 (right), 342, 344, 348; U. S. Department of Commerce, Coast and Geodetic Survey, 156; U. S. Department of Commerce, National Bureau of Standards, 84; U. S. Department of the Interior, Geological Survey, 162, (and W. G. Pierce) 132, (and W. T. Lee) 157, (and I. C. Russell) 159, 182, (and J. K. Hillers) 163, (and M. R. Campbell) 164, (and W. C. Alden) 166, 175, (and G. K. Gilbert) 169, (and W. C. Mendenhall) 177, (and C. D. Wolcott) 181; U. S. National Museum, 134; Visual Education Service, 158, 449, 450, 501; Walker Museum, University of Chicago, 170; Westerlin & Campbell Company, 297; Wide World Photos, 183, 233, 234; Yerkes Observatory, University of Chicago, 13, 15, 16, 19, 21, 25, 37, 40, 46, 58, 64; York Ice Machinery Corporation, 260.

The drawings were made by Raymond Craig, Ralph J. Rice, and Helen Snyder.

FINDING THE MEANINGS OF THINGS

Did you look at the frontispiece of this book? The frontispiece is opposite the title page. On it you will find a collection of stories about science that were printed in newspapers and magazines. If you did not look at this page very carefully, turn to it now and examine it. Are there any words whose meanings you do not know? Do you know what *vaccine*, *bacteria*, *satellite*, *infra-red*, and *glacier* mean? Are there any ideas that you do not understand? For example, do you know what the chemistry of a cell is? Do you know how a scientist might discover new heavenly bodies, such as satellites? Do you know what the newspaper writer meant when he said, "Nature has toppled off her balance again"?

Every day in the newspapers and magazines of our country there are many stories about science. These stories tell of the discoveries that scientists are making about the world in which we live. Some of these discoveries are so important that they are changing your life and the lives of millions of other people. Yet you cannot read these stories and understand them unless you know the meanings of science words and have accurate science ideas.

But understanding science in newspaper and magazine stories is not the only reason for learning science. The winds blow, rain or snow falls, you become ill with some kind of sickness, you pour hot water over a glass and the glass breaks, you try to learn to float in water, and in countless other ways you meet science every day of your life. What do these happenings mean to you? Do you understand what makes them happen?

Almost ever since you were born, you have been trying to find out what things mean. You probably pestered your

parents by asking "Why?" "What is it?" "What makes it go?" "Where did it come from?" etc. You were trying to find the meanings of things. The science that you will study in this book will make the world mean much more to you. You will study about the sun and the stars, earthquakes and glaciers, submarine boats and disease germs, muscles, bones, and intestines, cattle-raising, corn-growing, and irrigation. If you use this book right, hundreds of things that have never meant anything to you will really mean something to you.

There is a second thing that the study of this science material should do for you. People often say that the study of science should teach boys and girls to think. But that is not quite correct. You have been thinking for a number of years. You will probably go on thinking. But it is not so certain that you have been thinking correctly and that you will think correctly in the future.

This book can do much to show you how to think. As you read how scientists have solved important problems, you will be able to see how to use your own mind. As you work out the experiments, exercises, and problems in the book, you will have many opportunities to do the same kind of clean-cut, careful thinking that a scientist does when he makes discoveries about the world.

Now this book is only a tool to help you do a job. The job is to understand the world in which you live and to learn how to think correctly. You know that you cannot do good work with a tool unless you know how to use it. Therefore you should, first of all, get acquainted with the way this book is made. Probably you used *Science Problems, Book One* last year or last semester. *Science Problems, Book Two* is made like *Science Problems, Book One*. The book is divided into units. Look at the titles of the units in

the table of contents, so that you will get a big picture of what you are going to study.

Each unit starts off with some *Introductory Exercises.* These exercises will help you to find out what you know and what you do not know. Turn to page 70 and notice that two of the exercises are marked by asterisks, thus, *1. Exercises marked this way are very important. They ask you questions about things you learned in *Science Problems, Book One.* You will need to know these things in order to understand the material in *Book Two.* If you cannot answer these marked questions, be sure to find the answers before you begin your study of the unit.

Following the *Introductory Exercises* comes a part called *Looking Ahead.* These pages will give you a general idea of what the unit is about, and they will tell you the big problems that you are to solve in your study of the unit. Then you come to the problems, which are divided into sub-problems. Each problem and sub-problem asks an important question about the world in which you live.

Scattered at various places in the unit are *Self-Testing Exercises.* Their name tells you what they are for. They help you to check yourself to see whether you are really understanding the material you are studying. The exercises will be much better tests if you will try to do them without looking back in the book. After writing the answers as well as you can, it is a good plan to look back to be sure you are right, or to find the ideas you did not remember. When you have done all the *Self-Testing Exercises* that follow a problem or a sub-problem, write the answer to the problem itself. Every student should do at least this much before going on to the next problem.

In every unit there are also *Problems to Solve.* These problems are harder tests of your learning. Usually the

answers cannot be found in the book. You must think them out by using what you have learned. Or you must do some scientific research; that is, you must experiment, make observations, talk to people who have information that you need, or read books.

At the end of each unit is an exercise called *Looking Back*. This is a summary exercise to help you gather together the big ideas of the unit and to show you whether you know the meanings of the new science words.

If you finish the unit ahead of your class, or if you have extra time outside of class, you will be allowed to do extra projects. You may then do some of the *Additional Exercises* at the end of the unit.

The stories of the lives of scientists and of the things they have discovered are as interesting as any stories ever written. In the back of the book on pages 547-554 you will find a list of books about science and scientists. They will tell you many things that are not told in this textbook, and you will be able to understand them because you have studied this textbook.

Talk with your teacher about your plans for independent work. He will often be able to suggest things to find out or to do about science in your own community. You can often help him, too, by finding things out for yourself and then telling the class what you have learned.

The real success of your work in science will be shown by: (1) how much you learn about science; (2) how well you can use what you learn; (3) how well you learn to work without being told just what to do.

Wilbur L. Beauchamp
John C. Mayfield
Joe Young West

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FIG. 1. People have always been interested in the earth, the sun, the moon, and the stars. For thousands of years they did not understand what these heavenly bodies were, but they collected a great deal of information about them. When the telescope was invented, men began to learn the explanations of the things they had seen in the heavens. In this unit you will learn some of the important things that scientists have discovered about the earth and the other heavenly bodies.

UNIT ONE

UNIT 1

WHAT IS THE RELATION OF THE EARTH TO OTHER HEAVENLY BODIES?

INTRODUCTORY EXERCISES

Before you write the answers to the Introductory Exercises, read again the directions for doing them on page vii.

1. Here is a list of different heavenly bodies and of some things that happen in the heavens. Copy the ones that you have actually seen in a column headed *Observed.* Copy those that you have heard about but have not seen in a column headed *Have Heard About.* Copy the others in a column headed *Do Not Know About.*

Star	Planet	North Star	Eclipse of sun
Meteor	Planetoid	Falling star	Eclipse of moon
Venus	Satellite	Big Dipper	Phases of moon
Sun	Nebula	Constellation	Change in length of day and night
Comet	Jupiter	Rising sun	
Moon	Meteorite	Setting sun	

2. Write a sentence that tells something important about each item in the column in Exercise 1 headed *Observed.*

3. Write a sentence that tells what you have heard about each item in the column headed *Have Heard About.*

4. The earth has two kinds of movements. Can you name them? If you can, how could you tell by your own observations that these two movements were taking place?

5. How can you tell by your own observations that the earth is round?

6. Is the earth turning from *east to west* or from *west to east?* Give a reason for your answer.

7. St. Louis, Missouri, is west of Washington, D. C. If you traveled from St. Louis to Washington, would your watch be an hour fast or an hour slow when you reached Washington? Why?

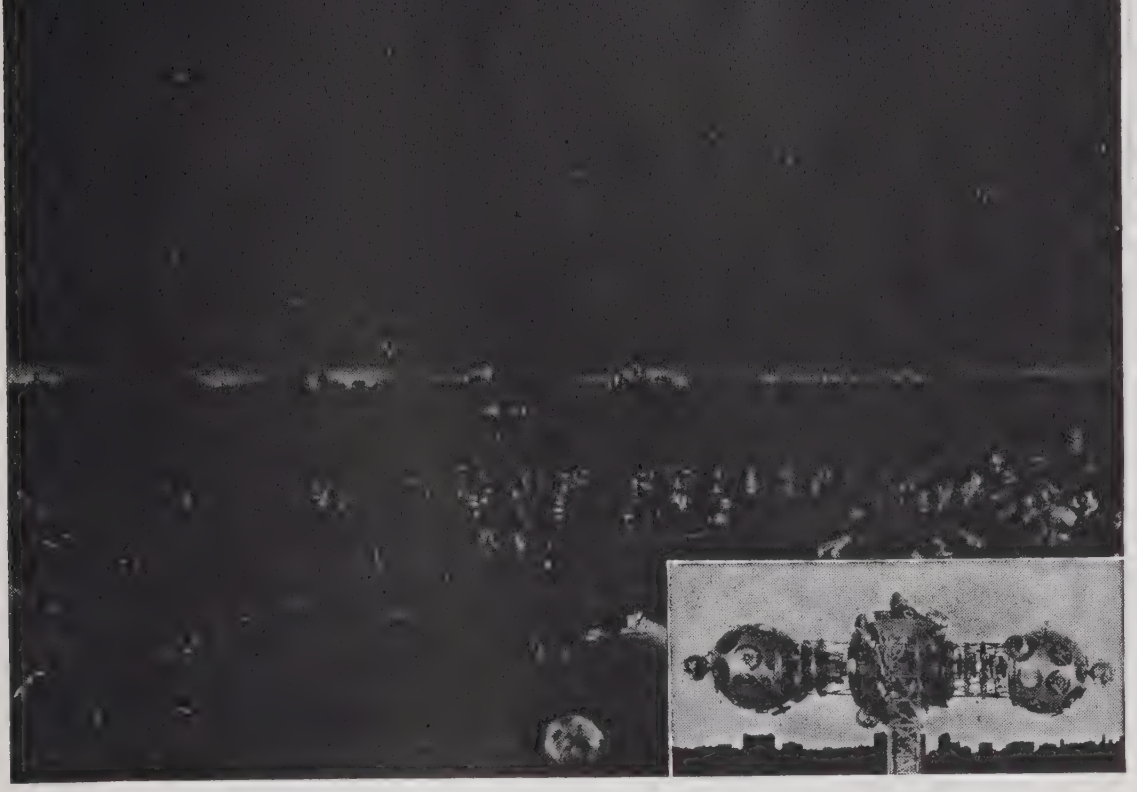

FIG. 2. If you ever visit a *planetarium*, you will take part in a scene such as this. The inset in the corner shows you the projection machine, which looks like a large dumbbell. From the center of the room it throws images of the stars upon the dome above. The planets, moons, and sun are projected, too. All these heavenly bodies are made to travel across the "sky" in the correct way but much faster than they really move in the heavens.

LOOKING AHEAD TO UNIT 1

ALMOST everyone spends many hours of his life wondering about the world we live in. Even savage people who can neither read nor write are puzzled by the sun, the moon, the stars, and the coming of day and night and of the seasons. We know this because they tell stories to explain why the moon changes its shape, why the stars "come out" at night, why the sun "goes down," and other things that they see happening from day to day and from month to month.

Men and women and boys and girls have always wondered about the earth and the heavens. Books and other records made by people thousands of years ago tell us that these ancient ancestors of ours were asking themselves the same questions about the world that we

FIG. 3. This old engraving, made in 1560, shows an early astronomer in his study. He seems to be studying and checking the ideas of other scientists. Perhaps he is going to make a chart showing the probable locations of the stars and other heavenly bodies that he has observed.

ask today. The human mind is always the same wherever you find it. It is a questioning mind. It wants to know why. It is not satisfied with just knowing that things do happen. It wants to know what causes things to happen in the way they do.

Of course, a few thousand years ago men had few ways of satisfying their curiosity about what they saw. They had no telescopes, microscopes, and other scientific instruments to help them discover the facts that they needed to answer their questions. What is more, in those days no one knew enough to take the facts they did have and explain them correctly. So men made up explanations, and people believed them. These explanations were nothing more than guesses, or they were just "imaginings," like fairy stories.

As time went on, men gathered a great deal of information about the stars and the other heavenly bodies. Clever men, called *astrologers*, were able to take this information and foretell when an eclipse was coming,

where the stars would be at different times of the year, and many other events concerning the heavenly bodies. People believed that if astrologers could foretell happenings in the heavens from the study of stars, they could also foretell events in people's lives. Until a few hundred years ago every king had his astrologer, whose advice was asked on all matters of importance.

Of course, most of us know now that the position of the stars or the planets has no influence on our lives. But even today you will find people who believe in *astrology;* that is, they believe that their future can be foretold by the positions of the stars on the day they were born. This is an example of how old ideas, even though they are proved to be false, are believed and passed on from generation to generation.

For thousands of years people had wrong beliefs about the sun, the earth, and the stars. But there were always a few honest, careful thinkers who tried to find the true answers to the questions that came up in their minds. Because of these men, a new science gradually developed, the science of *astronomy.* When the telescope was invented in 1608, the astronomer had an instrument that helped him to prove or disprove many of the ideas that were commonly believed. With this instrument he also learned many new facts. The science of mathematics had been developed, and astronomers could "figure things out" in ways that they had never before been able to use. Today, by means of photography the astronomer can take pictures of the stars and of other heavenly bodies and study them. He can even get pictures of stars that he cannot see!

In this unit you will find out some of the things that scientists have discovered about the earth and the other

heavenly bodies. You may wonder why the simple explanations that you will read in this book did not occur to the wise men of long ago. But you must remember that scientific knowledge grows slowly. The knowledge that we have today is the result of hundreds of years of experimenting and thinking by the wisest men of each generation.

Problem 1:

WHAT IS THE EARTH?

WHAT IS THE EARTH MADE OF? When anyone uses the word "earth" or "world" in speaking to you, what do you think of? Usually a person thinks of the entire earth as being much like the place in which he lives. If he lives in the mountains, he thinks of mountains. If he lives on the level plains or on the seashore, other pictures of the earth flash into his mind. Of course, such a person is not thinking of the whole earth. He is thinking of only a very small part of it.

But even if you traveled all over the world, you would not see much of the earth. You would see only the outside part. Beneath your feet would be 8000 miles of soil, rock, and other materials. No one has ever seen all of that, and no one ever will see all of it. Men have never seen more than the tiniest part of the millions of square miles of ocean bottom. Really, then, men have never seen very much of the earth. But science has made it possible for them to find out many things about the parts they have never seen and probably never will see.

The part of the earth that is most familiar to us is the land, or solid part, because that is the part upon which we live. We know that there are a great many different kinds of land forms, such as mountains, hills, plains, valleys, and plateaus. We are not so familiar, however,

25,000 MILES AROUND
8000 MILES THROUGH
¾ OF EARTH'S SURFACE COVERED WITH WATER
FROM DEEPEST OCEAN TO HIGHEST MOUNTAIN IS ABOUT 12 MILES

FIG. 4. On the globe are some interesting facts that you should know about the whole earth.

with what is deep in the earth. Of course we know that minerals, coal, and oil are found in the earth. But the deepest oil wells go down only about three miles into the 8000 miles of earth that lie beneath our feet. What about the center of the earth? Is it solid or liquid? What kinds of materials are found there?

For a long time scientists believed that the center of the earth was in a liquid state. They knew that the farther down one goes into the earth, the hotter it gets. They also saw melted rock pour out of volcanoes. These facts led them to believe that the center of the earth was liquid. In recent years, however, experiments have been performed that seem to show that the interior of the earth is solid.

The core of the earth seems to be made of very heavy material. It is probably a mixture of nickel and iron. Around this core there are other layers containing mate-

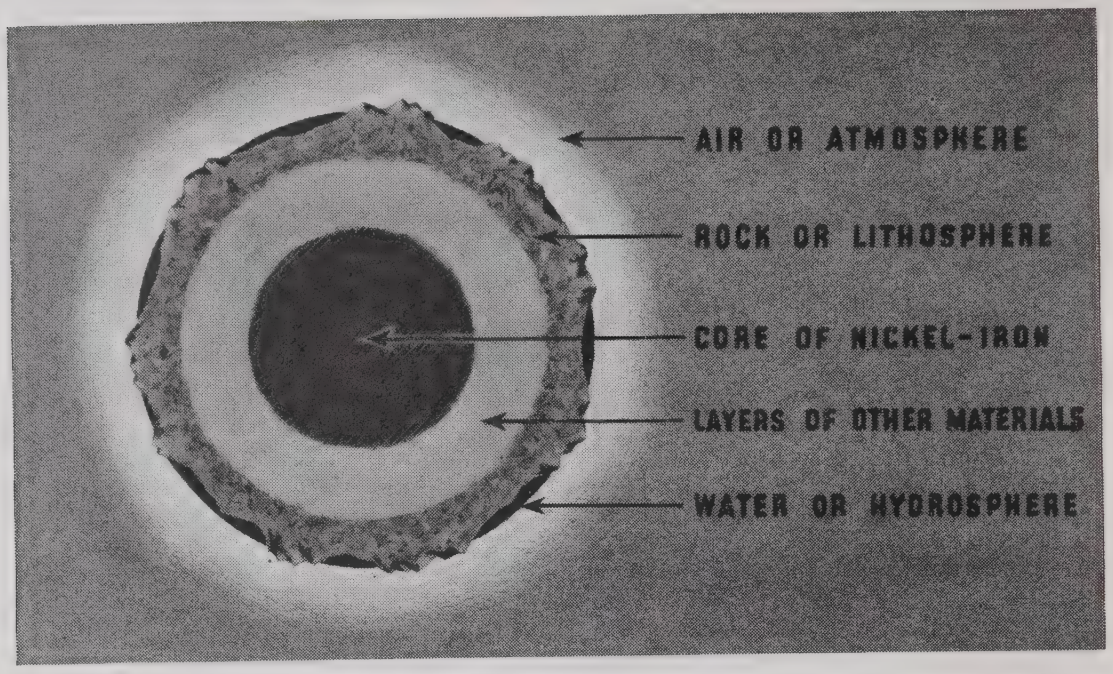

FIG. 5. This slice through the earth shows how it is divided up into air, water, rock, and solid materials. The drawing exaggerates the depth of the air and the thickness and unevenness of the rock layer.

rials such as iron, silicon, and magnesium. These layers are covered by rock material. In some places, such as mountains, this rock can be seen. At other places the rock is covered with a thin layer of soil upon which plants and animals live.

As you know, much of the solid part of the earth is covered with water. This water covering is also part of the earth. If you look carefully at a globe map, you may be surprised to see how much of the earth's surface is water. Actually, only about one-fourth of the earth's surface is land. The remaining three-fourths are covered with water varying in depth from a few inches to more than six miles.

But the earth is more than land and water. Surrounding the earth is a layer of air that is just as much a part of the earth as the land and the water. Scientists do not know how thick this layer of air is. Some of them think

it goes out about seventy-five miles; others have estimated that it is 300 miles thick. Wherever the earth goes, this covering of air goes, too. So you can see that the air really belongs to the earth. Out beyond the air is empty space.

If you want to be really scientific, you can learn the names given by the scientist to the different parts of the earth. The solid part is called the *lithosphere*, which means "rock sphere"; the liquid part, the *hydrosphere* or "water sphere"; and the gaseous part, as you know, the *atmosphere* or "vapor sphere."

WHY DO WE BELIEVE THAT THE EARTH IS A SPHERE? Since you first began to study geography, you have known that the earth is shaped like a ball. To be scientific, we say that the earth is a *sphere*. You probably have never thought of doubting this statement. But you know that up to the time of Columbus and, indeed, for many years after, most people thought that the earth was flat. They thought that if you walked in one direction far enough, you would come to a place where you would fall off the earth. This may seem a foolish idea to you. But suppose that someone did not believe you when you told him that the earth is a sphere. Suppose he asked, "How do you know?" How could you prove that you are right?

If you tried to convince your friend that your statement was true, it would be necessary for you to give some evidence for your belief. That is, you would have to tell him some facts and explain why these facts gave you a reason for your belief. Of course, the easiest way to convince a person is to show him so that he can see for himself. But you cannot take a person far enough out into space so that he can see the shape of the earth. He cannot

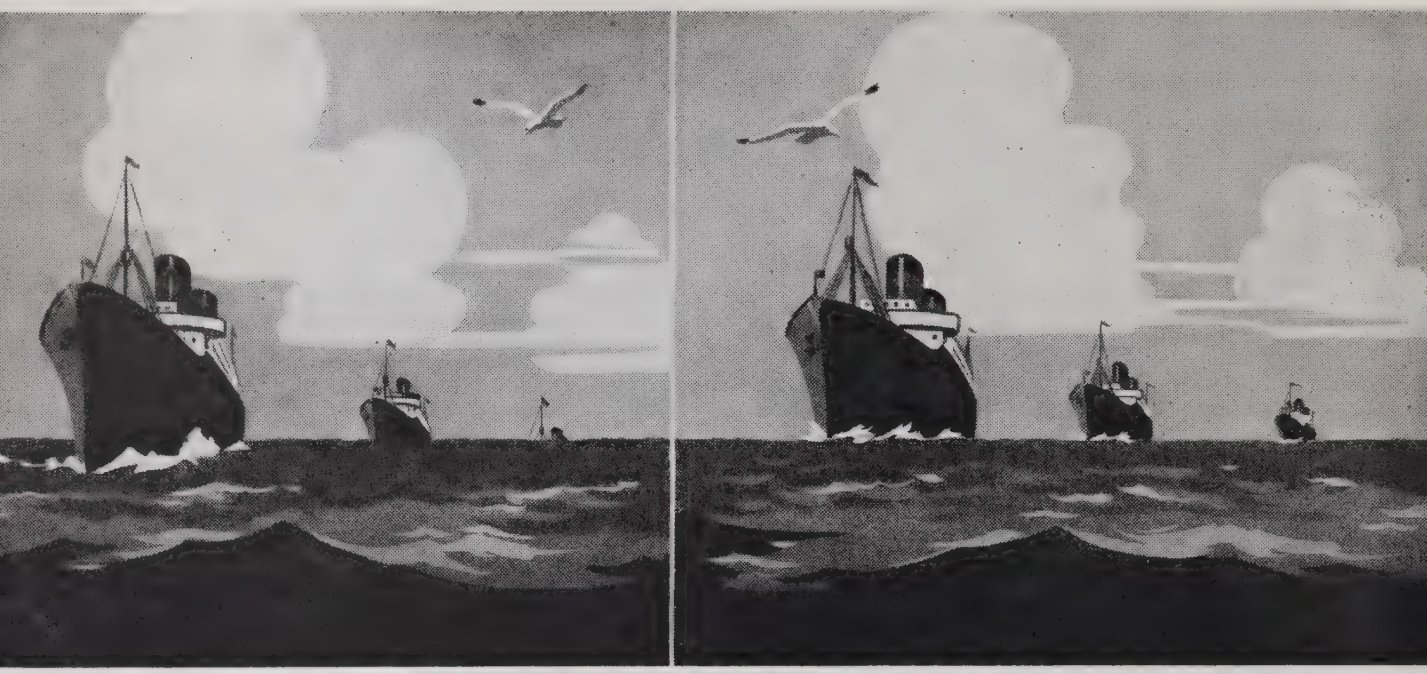

FIG. 6. The picture on the left shows how three ships approaching harbor from different distances look on the earth as a sphere. The picture on the right shows how the ships would look if the earth were flat.

see that the surface is curved, because the earth is so large that the surface curves cannot be seen. So you must think of other ways to convince him.

If you lived near a large body of water, such as the ocean or one of the Great Lakes, you could have your friend watch a ship disappear over the horizon. If you have not already done this yourself, you should do it when you have an opportunity. In making this observation, try to answer this question: "Does the whole ship get smaller and smaller and finally disappear, or does the lower part of the ship disappear first, then the middle part, and finally the upper part?"

Now let us see how watching a ship helps us to prove that the earth is a sphere. If the surface of the earth were flat, the ship would remain in sight, gradually growing smaller and smaller. At last it could not be seen because

of the great distance. But this does not happen; so we may be certain that the earth is not flat. The only kind of surface on which the lower parts of a ship will disappear first is a curved surface. You can see how this happens if you hold a tennis ball in front of your eyes at arm's length and then move a match stick across the top and down on the other side of the ball (Figure 7). Of course, no single observation would prove that the earth's surface is curved everywhere, as it must be if it is a sphere. But observations at any point on the earth's surface, and at all directions from this point, do show that ships always disappear in this way. Therefore, we must conclude that the earth is a sphere.

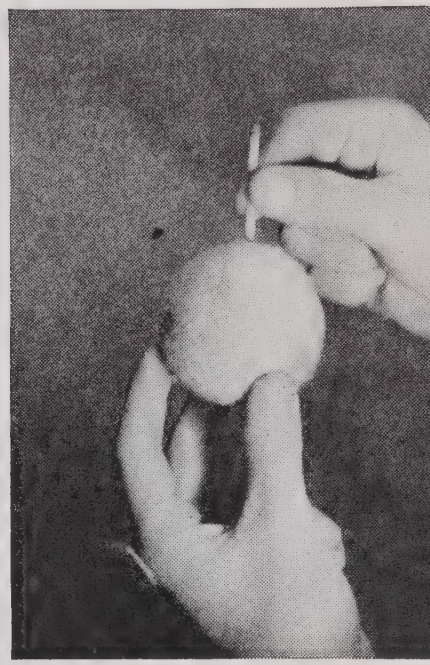

FIG. 7

There are still other kinds of evidence to show that the earth is a sphere. Ferdinand Magellan, a Portuguese explorer, proved it when his ship completed the first voyage around the earth in 1522. Sailing westward from Portugal, the ship at last came back to Portugal from the east. Now, practically everyone knows that if a ship or an airplane travels long enough in one direction, it will return to the place from which it started. Such a happening could take place only on the surface of a sphere.

Still another reason for believing that the earth is a sphere is found in the way the earth is lighted. You know that the earth does not give out light of its own, as the sun does. If it did give out light of its own, we would have no night. The earth is lighted by the sun.

Now let us see how the light from the sun would fall on the earth if the earth were flat or box-shaped instead of being a sphere.

Experiment 1. *How Is the Earth Lighted by the Sun?* (*a*) Push a steel knitting needle or a straight piece of wire about six inches long through a small rubber ball. Hold the knitting needle in an upright position about three feet from a strong light. How much of the ball is lighted? Rotate the ball slowly. Is the same amount of the surface of the ball lighted all the time while the ball is being turned?

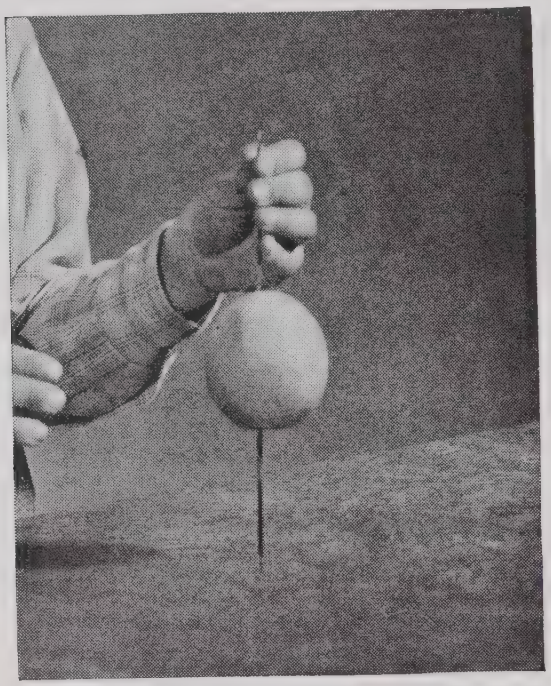

Fig. 8. Experiment 1

b) Push the knitting needle through the centers of opposite sides of a small cubical cardboard box. Hold the needle in the same position as before and the same distance from the light. Rotate the box slowly. When one side of the box faces the light, how much of the box is lighted?

When the box is rotated, does the part that is turned toward the light become lighted gradually, as the ball does in part *a*, or does one whole side of the box suddenly become lighted?

From what you have seen of dawn and dusk, does the earth become lighted as in part *a* or as in part *b* of the experiment?

If a box or other object with flat surfaces is used, the side becomes suddenly lighted when it is turned toward the light. Just as suddenly all of the side becomes dark when it is turned away from the light. When a sphere is used, the lighted portion shades off gradually into the dark. You have seen the same thing happen on the earth in the late afternoon and in the early morning. It gets gradually lighter in the morning and gradually darker at night.

If the earth were flat or box-shaped, daylight would come suddenly, as when a whole room is quickly lighted by turning on an electric light. Darkness would come just as suddenly. So here is another reason for believing that the earth is a sphere.

What you have just read gives you only a few of the reasons for believing that the earth is a sphere. Scientists have much more evidence to prove the shape of the earth. Perhaps the best evidence is what we see when there is an *eclipse* of the moon. When this happens, the shadow of the earth is seen on the moon. The edge of the shadow is curved. Such a curved shadow could be made only by a circular or spherical body. Later in this unit you will learn why we can sometimes see the shadow of the earth on the moon.

FIG. 9. The curved shadow of the earth on the moon

How scientists have learned that the earth is a sphere is a good example of one of the ways in which scientists work. No person had ever been far enough out in space to tell about the shape of the earth. But scientists and other people had seen certain things happen, such as the disappearance of a ship at sea, the way in which the earth is lighted, and the shadow of the earth on the moon. These were facts that everyone knew about. Scientists tried to think out a way to explain these facts. The only way in which scientists could account for them was by believing that the earth is a sphere. This explained all of the facts that scientists could gather; so they accepted it as a true explanation.

Recently, however, scientists have had further proof that they were correct in their belief about the shape of

the earth. In November, 1935, Captain Albert W. Stevens and Orville A. Anderson went up in a balloon that reached the height of 72,395 feet, or 13.71 miles, above sea-level. At this elevation they took a picture of the earth. The photograph actually showed a slight curving of the earth at the sky-line. There can no longer be doubt as to whether the earth is a sphere. Actual photographs show that it is a sphere.

Self-Testing Exercise

1. Give the best word picture of the earth you can on one-half page of notebook paper.

2. State four reasons for believing that the earth is a sphere.

Problems to Solve

1. Figure 10 shows that the sun's rays shine almost straight down at the equator when they are quite slanting near the poles of the earth. Make a drawing to show how the rays would strike the earth if the earth were flat.

2. Find out about the different trips that have been made to go around the earth in the shortest possible time. What is the record now? Since the earth is a sphere, how should one go around it really to establish a round-the-world record?

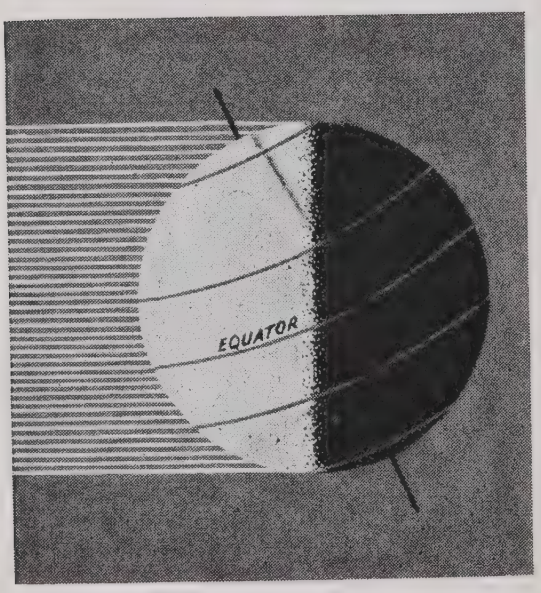

FIG. 10. Diagram for Problem 1

3. If the earth were a flat surface instead of a sphere, what would happen if you traveled far enough in any one direction?

4. See if you can find out about ocean depths. Where are the deepest spots in the oceans? Find out also the highest spot on the earth's surface.

FIG. 11. Great flaming masses of gases are frequently shot off into space thousands of miles from the surface of the sun. It is fortunate that we are far from the sun. If we were very close, one such storm would destroy the earth.

Problem 2:

WHAT IS THE SOLAR SYSTEM?

AS YOU look into space on a clear day, there is one object that you always see. This object is more than 93,000,000 miles away, but you could not live without it. Fortunately, we could not get away from this object if we tried. It holds the earth as a prisoner. Year in and year out, the earth is traveling at a speed of over 1000 miles a minute around and around this object. As you have guessed, this object is the sun. It is the center around which the earth and certain other heavenly bodies keep up a never-ending journey. The sun and the other heavenly bodies that revolve ceaselessly around it are called the *solar system.*

WHAT IS THE SUN? Have you ever wondered what the sun is really like? You know that the sun is very hot, because it gives the earth a great amount of heat and light even though it is millions of miles away. To give us this enormous amount of heat and light at so great a

distance, the sun must be very much hotter than anything we can imagine; and so it is. Scientists have measured the temperature of the outside of the sun. It is about 10,000° F. They believe that the temperature in the center of the sun is many million degrees. At this temperature solids and liquids could not exist. So the sun must be a huge mass of extremely hot gases.

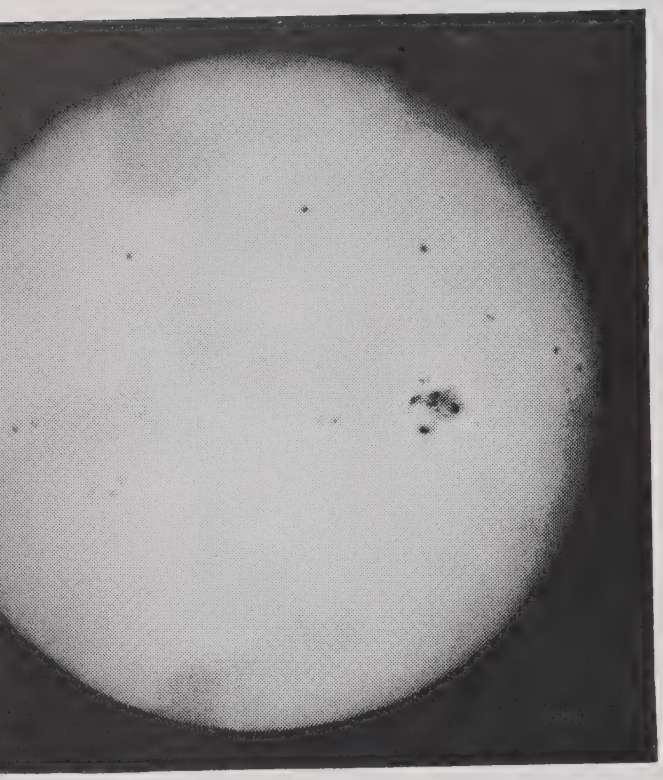

Fig. 12. Astronomers say that sun-spots of average size, such as shown in this picture, would hold forty planets the size of the earth.

You would never guess how huge this ball is, but scientists can tell you because they have actually been able to measure it. They say that it would take more than 100 bodies the size of the earth placed side by side to equal the diameter of the sun. If the sun were hollow, there would be room enough inside it for more than 1,000,000 earths. It looks small to us because it is so far away.

Photographs of the sun, taken through powerful telescopes, have shown scientists many interesting things about what is happening on it. For one thing, there are at times great swirling masses of gases on the surface of the sun. Scientists speak of these as "storms" on the sun and call them *sun-spots* (Figure 12). These storms are called "spots" because in the photographs they show as dark spots. Many scientists think that sun-spots cause unusual weather conditions on the earth.

You have often seen the *stars* in the heavens at night. Astronomers find out about the stars by studying the light that comes from them. They find that it is the same kind of light as the light from the sun. From this they know that the sun itself is a star. The sun looks larger and brighter than the other stars because we are close to it. The sun is our nearest star.

WHAT ARE THE PLANETS? Long before telescopes were invented, people noticed heavenly bodies that looked like stars, but that were different from stars in the way they moved across the sky. They gave the name *planets*, or wanderers, to these bodies.

Since scientists began to study the heavens with their telescopes, they have learned many things about the planets. They have discovered three planets that are too dim to be seen without a telescope. They have found that the planets seem to move among the stars because the planets are traveling in paths around the sun. They have learned that the earth itself is a planet. We now know that there are at least nine planets. Pluto, the last one to be discovered, was not found until 1930. And there may be others still farther from the sun.

So far as astronomers have been able to tell, the planets are all made of material somewhat like the earth. Some of them have an atmosphere with clouds, as the earth has. Since the planets are much like the earth, they cannot give out light as the stars do. We can see them "shining" in the night skies because the sun shines on them and they reflect the light back to us.

Figure 13 shows a diagram of the nine planets and the paths, or *orbits*, in which they revolve about the sun. As you can see, two of these planets, Mercury and Venus, are much nearer the sun than the earth is; therefore, they

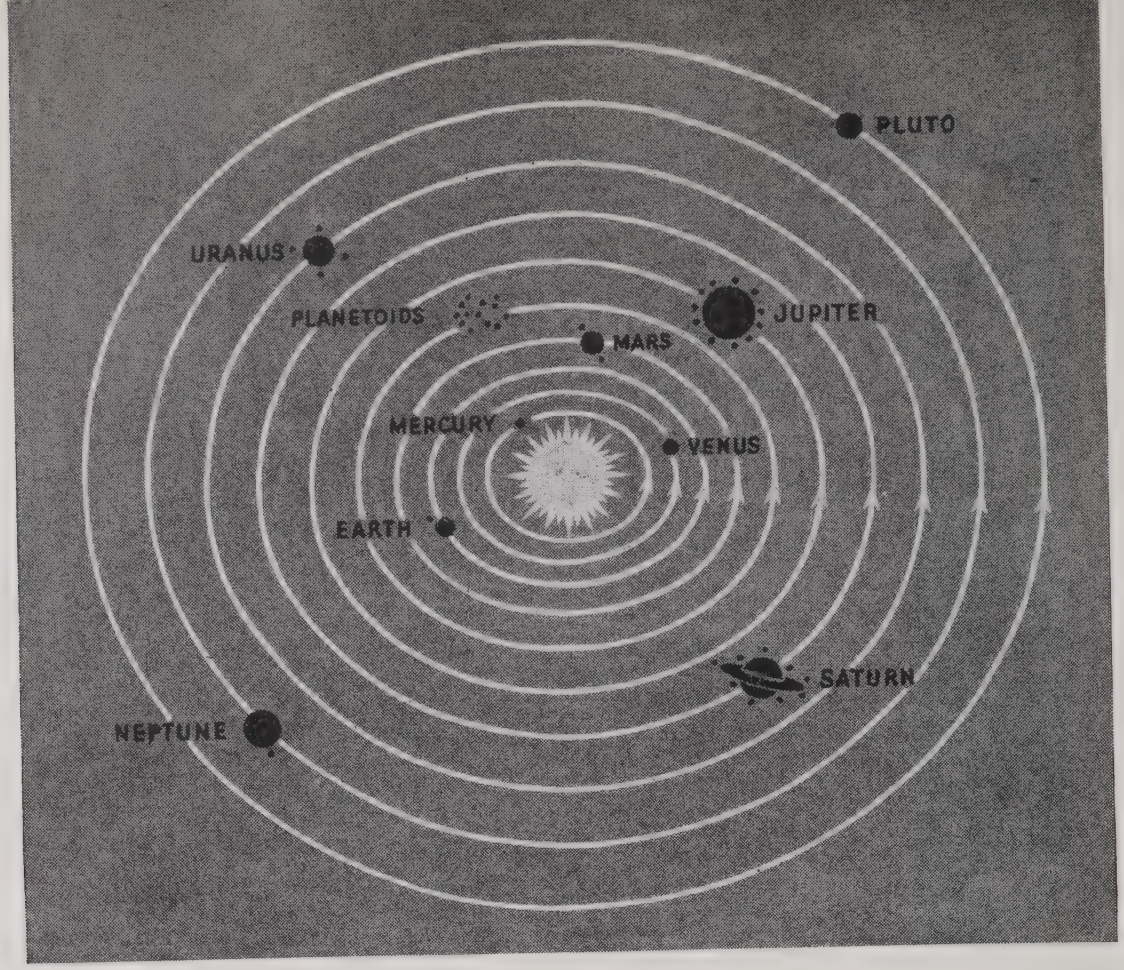

FIG. 13. The earth and the eight other planets revolve about the sun in the same direction. In this drawing it was not possible to show the distances between the paths of the planets in their correct relations to each other. The chart on page 20 shows how far the various planets are from the sun. Pluto, the farthest from the sun, was discovered on January 21, 1930.

must be much hotter than the earth. Because these two planets are nearer to the sun, they do not have such great distances to travel to make a complete journey around the sun. Also, they travel faster than the planets farther away from the sun. So they complete their revolutions more quickly than the earth does. The earth is the third planet from the sun. We know that it travels around the sun once in approximately $365\frac{1}{4}$ days and that it turns on its own axis once every twenty-four hours.

Planets farther out from the sun are Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. They all have greater distances to travel in going around the sun than the earth does, and they travel slower than the planets

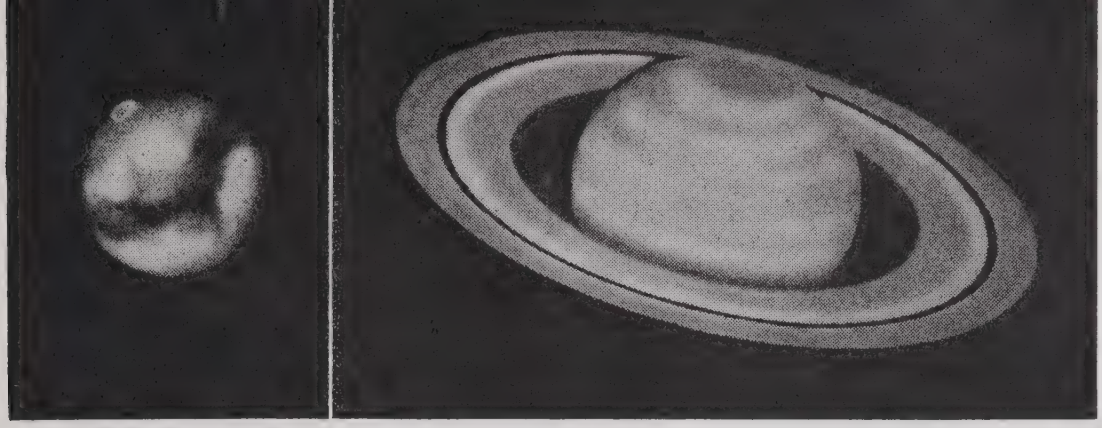

FIG. 14. Seen through a telescope, Mars, at the left, has these distinctive characteristics: reddish color, large dark markings, and white polar caps. These caps seem to appear and disappear at different seasons. Saturn, shown in the picture at the right, is interesting to us because of its rings. These rings seem to be very thin and made up of dust-like particles.

nearer the sun; so they require longer periods in which to complete their revolutions. Because of their greater distances from the sun, they do not receive so much light or heat as the earth; therefore, scientists believe that they are colder than the earth.

By studying Table 1, page 20, you can learn the most important facts about the planets. As you can see, Mercury is the nearest of all planets to the sun. Its distance is about 36 million miles, while the distance of the earth is about 93,000,000 miles. Mercury is a small planet—only about half as large in diameter as the earth. It requires only eighty-eight days to go around the sun. In other words, Mercury goes around the sun about four times while the earth is going around once.

Mercury turns very slowly on its axis. The earth spins around once every twenty-four hours, but Mercury turns only once in approximately eighty-eight days. You can see that it turns upon its axis only once while it makes a complete revolution about the sun. Because of this, the same side of Mercury is always turned toward the sun. As a result, the side toward the sun must be extremely hot, and the side away from the sun must be extremely cold.

TABLE 1. Important Facts about the Solar System

Bodies	Distance from the Sun	Diameter in Miles	Revolution around Sun	Rotation on Axis	Approximate Temperatures	Appearance in Night Skies	Moons	Speed in Miles per Second
Sun	.....	864,392	.....	25 days	10,000° F. at surface	.....	....	.....
Mercury	36 million miles	3,009	88 days	Nearly 88 days	Hot on one side, cold on other	Reddish-yellow	0	29.7
Venus	67 million miles	7,701	225 days	224.7 days	Hot on one side, cold on other	White	0	21.7
Earth	93 million miles	7,918	365¼ days	23 hrs. 56 min.	Sufficient to support life	.....	1	18.5
Mars	142 million miles	4,339	687 days	24 hrs. 37 min.	Colder than earth	Red	2	15.0
Jupiter	483 million miles	88,392	11⅞ years	9 hrs. 53 min.	Very cold	Yellowish-white	11	8.1
Planetoids	200 or 300 million miles	20 to 300	2 to 13 years	Unknown	.....	Not usually visible	....	.....
Saturn	886 million miles	74,163	29½ years	10 hrs. 15 min.	Very cold	Reddish-yellow	8 and 3 rings	6.0
Uranus	1,782 million miles	30,193	84 years	10 hrs. 42 min.	Very cold	Barely visible to naked eye	4	4.2
Neptune	2,792 million miles	34,823	164½ years	15 hrs.	Very cold	Not visible to naked eye	1	3.4
Pluto	3,673 (?)	Less than 10,000(?)	247.7	Unknown	Very cold	Not visible to naked eye	?	2.9
The Earth's Moon	93 million miles(variable)	2,163	.....	27.6 days	Hot on one side, cold on other	Yellowish-white	....	.....

WHAT ARE PLANETOIDS? In addition to the sun and the planets, the solar system contains *planetoids*, *comets*, and *meteors*. In Figure 13, page 18, you will notice that there is a vast distance between the orbits of Mars and Jupiter. It seems as if there should be another planet between these two planets. Many astronomers believe that a planet once occupied such a position, but that it met with some kind of accident that broke it to pieces.

In the space between Mars and Jupiter scientists have found about 1100 small bodies that are like tiny planets. These bodies vary in diameter from 20 to 300 miles. They are called *planetoids*, which means little planets. They travel around the sun in their own orbits. Scientists think that these planetoids may be pieces of a big planet that once upon a time traveled around the sun between Mars and Jupiter.

FIG. 15. A comet is a glowing mass of gases with an enormous head and a tail that may be millions of miles long. A comet can be seen only when it is near the earth. The stars in the picture show as streaks because the camera had to be kept moving with the comet in order to get a picture.

WHAT ARE COMETS AND METEORS? Another strange kind of heavenly body that sometimes appears in the solar system is known as a *comet*. Scientists believe that comets are masses of gaseous material. Some of them have long gaseous tails that are always on the side away from the sun. Comets travel in very loop-shaped, or elliptical, orbits around the sun (Figure 16). Some of

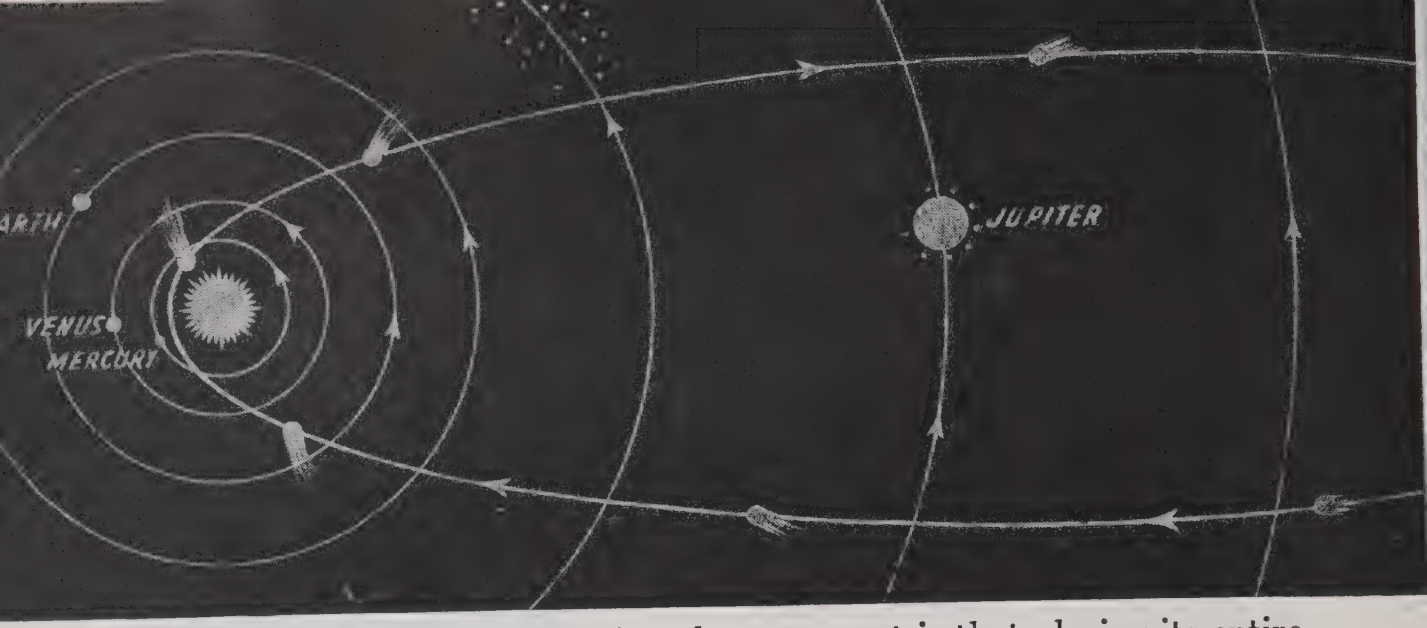

FIG. 16. The strangest thing about a comet is that, during its entire trip about the sun, its long tail streams away from the sun. When it approaches the sun, the tail is behind it. When it swings away from the sun, the tail is out in front.

them are known to return at intervals of from three to seventy-five years.

Meteors are heavenly bodies that we see more often. We usually call them "falling stars," but this name is incorrect. Stars do not fall. Meteors are really small bodies of material that fall from space into the earth's atmosphere. No one knows where they come from. Sometimes they are only as large as a pea; sometimes they weigh several tons. Only when these bodies fall into the earth's atmosphere do we see them. The air rubbing against them as they fall causes them to become very hot and give off light. Sometimes meteors fall to the earth. Then we call them *meteorites*. Some meteorites are found to be stones, and some are masses of metal, mostly nickel and iron. Usually the meteorites burn up, and only the dust that is left falls to the earth.

Moons, or *satellites*, are also found in the solar system. Moons are bodies that revolve around planets much as planets revolve around the sun. From the table on page 20 you can see that some planets have many moons. As you know, the earth has only one.

Self-Testing Exercises

1. Tell briefly what you think of when someone mentions the solar system.

2. How did scientists learn that the sun is itself a star?

3. Do scientists think that the inside of the sun is solid, liquid, or gaseous? Give one reason for their belief.

4. What is a planet?

5. Name the planets that have orbits inside the orbit of the earth. Name those that move outside the earth's orbit.

6. Which planet was discovered most recently?

7. Do planets give light themselves? Explain.

8. Name three ways in which Mercury is different from the earth.

9. Which planet would you expect to be warmest? Which one coldest? Why?

10. How are planetoids different from planets?

11. What is a comet?

12. What is a meteor? Why do meteors give out light?

FIG. 17. This meteorite is the largest ever seen to fall. It is two and one-half feet long and weighs 820 lbs. The largest known meteorite in America weighs thirty-six and one-half tons.

Problems to Solve

1. Which planet has the longest year? Which the longest known day?

2. Which planets were discovered with the help of the telescope? You can solve this problem from the reading and Table 1.

3. From Table 1 and from what you know about the planets make a list of the ways in which they are alike. Make also a list of the ways in which they are different from each

other. (One way in which they are different is in "Size." Do not say, "Mercury is smaller than the earth.")

4. Some of our airplanes now fly long distances at the rate of 200 miles per hour. If you could fly from the earth to the sun in such a plane, how many years would it take you if you flew 24 hours per day?

5. Draw circles to represent the sizes of the nine planets. Make the circle for Mercury one-fourth inch in diameter and calculate from Table 1 how large each of the other circles should be.

6. Light travels about 186,000 miles per second. How many minutes does the light of the sun take to reach the earth?

7. How are planets different from stars? List as many differences as you can.

8. Find in reference books as many interesting facts about Venus as you can. Do the same for Mars, Jupiter, and Saturn.

WHAT IS THE EARTH'S MOON LIKE? The heavenly body we notice most often is the sun. Unless the sky is very cloudy, we see the sun every day, and it always looks much the same to us. But our nearest neighbor in the heavens is the moon. Strangely enough, sometimes we do not see it at all. When we do see it, we find that it apparently changes its shape from day to day. Sometimes it looks like a full circle, at other times like a half circle, and at other times like a crescent. Of course we know that the moon does not change its shape. Why, then, does it seem to do so?

As you look at the full moon in the sky, it seems to be about the same size as the sun. Actually, its diameter is only a little over 2000 miles, only one-fourth the diameter of the earth. It would take about 400 moons side by side to make a body with the same diameter as the sun. The

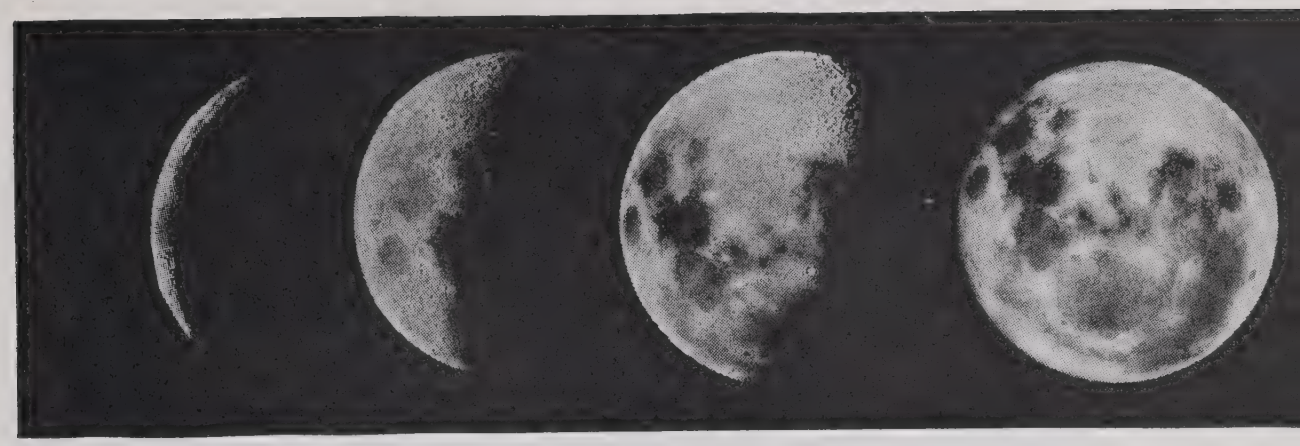

FIG. 18. This picture shows how the moon changes from a crescent-shaped new moon to a round full moon. Each of these different shapes is called a *phase* of the moon. The moon is shown here at the ages of 3.85 days, 5 days, $9\frac{3}{4}$ days, and 16 days.

moon appears to be as large as the sun because it is so much closer to us. It is only about 240,000 miles from the earth. This seems like a great distance, but it is really a very small distance as compared with the 93,000,000 miles to the sun.

Moonlight, as you know, is not nearly so bright as sunlight. The moon is not made of hot gases; it gives off no light of its own. We see the moon because the light from the sun strikes it and this light is reflected to the earth. Imagine that you are in a dark room with a large, very white ball and a bright flashlight. You then hang the ball up by a string and turn the flashlight on the ball. You find that the wall behind you is lighted up with light reflected from the ball. The moon reflects the light of the sun to us just as the ball reflects the light from a flashlight.

When the moon is full, you can see irregular spots that appear darker than others. If your imagination is good, you can see that these spots make the eyes, nose, and mouth of the man in the moon. If you imagination is still better, you may see the lady in the moon. Until tele-

FIG. 19. Seen through a telescope, parts of the moon's surface have a pitted appearance. These pits are immense craters. Other parts are rough, while others are smooth. Figure 20 gives the name and location of several craters, as well as of some mountains and plains.

scopes were invented, no one knew why these spots were there. Through the telescope, however, we can see that these spots are really chains of mountains, great craters, and vast flat spaces.

What you have just read might lead you to believe that the moon is somewhat like the earth. It is, however, quite different. The mountains are more rugged, and they rise almost straight up from the plains. One of the most amazing things about the surface of the moon is the tremendous number of craters. Over 30,000 of these craters have been found. They are many times as large as any of the volcano craters found on earth. One of the moon's craters is seventy-five miles in diameter, while there are hundreds of smaller craters that are from five to twenty miles in diameter.

Story-tellers often write tales of the strange creatures on the moon. These stories, however, are not based on any facts that we know. The moon can have no living creatures on it, because it has no air, water, or soil. Our nearest companion in space is just a huge ball of barren rock.

FIG. 20. By the numbers on the map you may find the names of the principal surface features of the moon. The craters are: 1. Tycho, 2. Grimaldi, 3. Copernicus, 4. Eratosthenes, 5. Plato. The mountains are: 6. the Alps, 7. the Apennines. The plains are: 8. Crisium, 9. Fecunditatis, 10. Nectaris, 11. Tranquilitatis, 12. Serenitatis, 13. Imbrium, 14. Nubium.

WHY DOES THE MOON SEEM TO CHANGE ITS SHAPE? You know that the moon, like the earth, is a sphere. At any one time only half of it can be lighted by the sun. You also know that the moon revolves around the earth in twenty-seven and one-third days. As it travels around the earth, we see different parts of its surface lighted by the sun. You can best understand why this is true by doing an experiment.

EXPERIMENT 2. *Why Does the Moon Appear to Have Different Shapes at Different Times?* Place a strong light upon a stand about four feet high to represent the sun as in Figure 21. You are to represent the earth. Hold a tennis ball at arm's length from you to represent the moon. Stand with your face to the

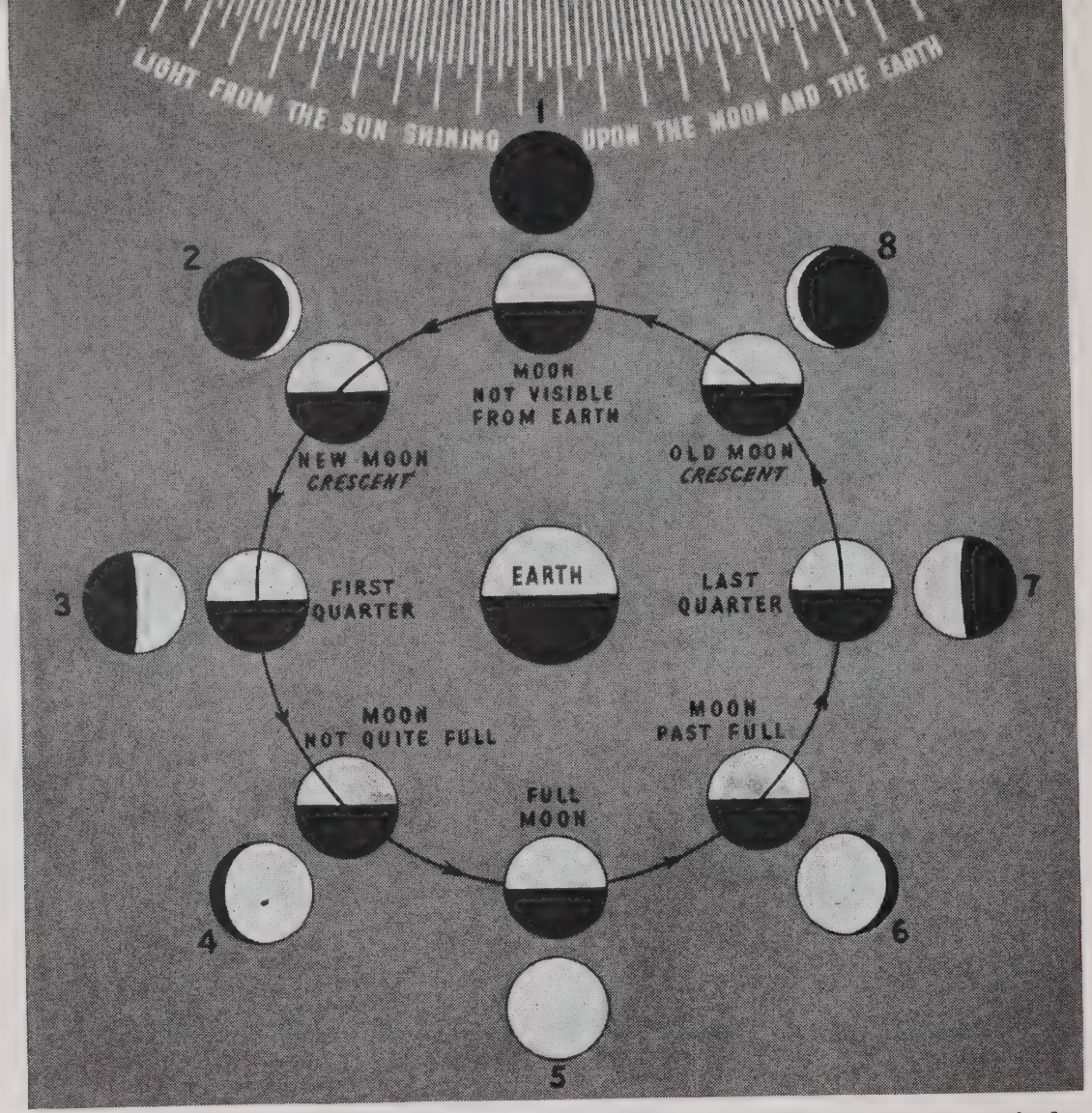

FIG. 21. The outer circles show the shape of the lighted part of the moon as it appears to us on the earth at different times of the month. The inner circles show the moon as it is actually lighted. The half that is toward the sun is always lighted. The only portion of this lighted half that is visible to us on the earth is that inside the black line.

light and hold the ball between you and the light, as shown in position 1, Figure 21. The half of the ball nearest you should be entirely dark.

Now turn toward your left, away from the light, stopping at each of the numbered positions shown on the diagram. Hold the ball high enough above your head to receive the light in position 5. Can you see each of the shapes shown in the outer group of circles as you change positions? Sketch the shape of the lighted parts of the ball in each position. How do these shapes compare with the shapes of the moon as it appears to you at different times?

Figure 21 and your experiment will help you to see why the moon appears to change its shape. When you held the tennis ball between yourself and the light, the half of the ball nearest the light was lighted, but the part toward you was dark. In the same way, you cannot see the moon when it is between the earth and the sun. With the ball held at one side, you could see half of the lighted surface. When the earth, sun, and moon are in this position, you see the *quarter moon*.

When you were between the light and the ball, you could see all of its lighted part. When the earth is between the sun and the moon, you see the *full moon* because the light from the sun shines over the earth and on to the moon. As you moved the ball around, you found that you could see different amounts of the lighted parts. This is what happens when the moon revolves around the earth.

FIG. 22. An eclipse of the moon

Sometimes the sun, moon, and earth get in a direct line, as shown in Figure 22. Then the moon gets in the earth's shadow. This causes the moon to appear partly or totally darkened. This is called an *eclipse* of the moon. At other times the sun, moon, and earth get in the direct-line position that is shown in Figure 23. The moon comes between the earth and the sun. This throws the moon's shadow upon the surface of the earth. When we look at the sun, we see its surface totally or partly darkened,

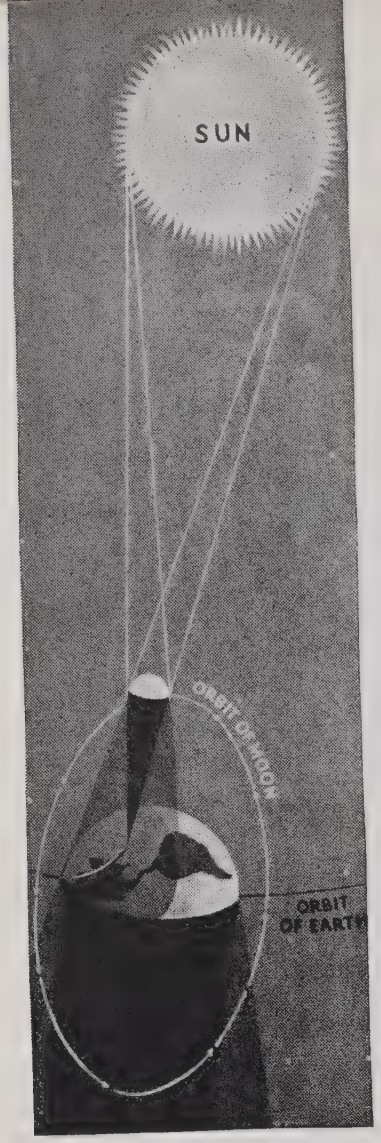

FIG. 23. In August, 1932, the moon caused a total eclipse of the sun along a path in eastern Canada and New England.

depending upon where we are upon the earth. Then we have an eclipse of the sun.

HOW DO THE MOON AND THE SUN CAUSE TIDES? As you know, the earth has *gravity*. That is, it attracts everything toward itself. The gravity of the earth holds the moon in its orbit. Scientists have found that all the heavenly bodies have an attraction for other bodies. The sun holds the planets in their orbits, and each planet attracts its moons. Our moon has an attraction of its own and pulls on the earth. It pulls both the land and the water, but the water moves more easily than the land. Therefore, the water is pulled up on the side of the earth nearest the moon. As the earth turns, the pulled up water soon reaches the shore and makes a tide there. When this happens, we say that there is a *high tide*.

The earth turns rapidly upon its axis, and soon the part of the ocean that was nearest the moon (where the water bulges out) turns away from the moon. Then the water settles back, and we have *low tide*. The strangest thing about the tides, however, is the high tide on the side of the earth away from the moon. The moon seems to pull harder on the solid part of the earth than it does on the water that is on the side farthest away from the moon. Thus, the water also bulges out on the side away from the moon. When the earth

turns half-way around so that we are farthest away from the moon, we have high tide again.

As the earth turns upon its axis, two high tides take place at any point on the ocean's shore every twenty-four hours and fifty minutes. Of course, there are also

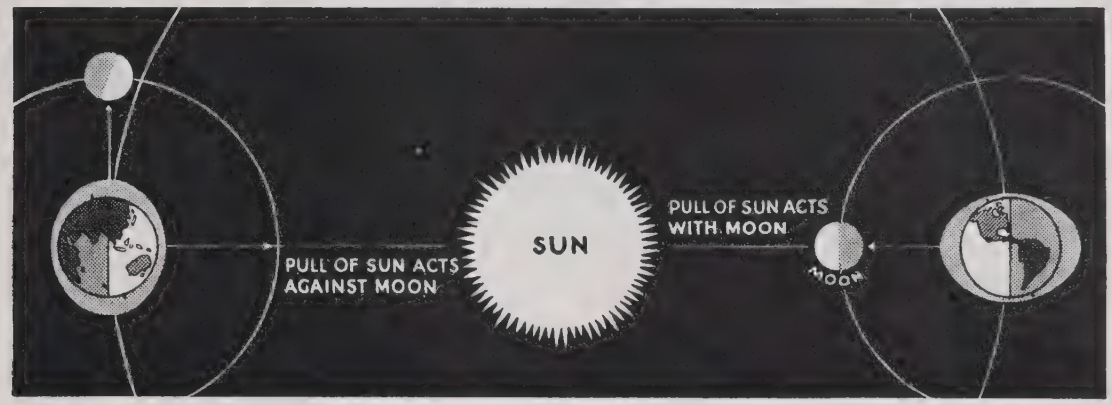

FIG. 24. This diagram shows how the sun and the moon pull together and cause high tides at certain times of the month. It also shows how they work against each other and cause low tides at other times during the month.

two low tides during this same period of time. So we have a high tide and a low tide alternating about every six hours and twelve minutes.

The sun's attraction for the earth also affects the tides. Twice a month it makes the tides unusually high, and twice a month it works against the moon so that tides are unusually low. Figure 24 shows the sun, moon, and earth when the tides are unusually high and unusually low.

Self-Testing Exercises

1. What is the difference between sunshine and moonshine?
2. Why do we believe that there is no life on the moon?
3. Write a paragraph telling why the moon appears to change its shape.
4. What can people on the earth see happening during

FIG. 25. The same seashore is shown at low tide, on the left, and at high tide, on the right.

an eclipse of the moon that they cannot see at other times? Why does this happen?

5. Answer Exercise 4 for an eclipse of the sun.

6. How many high tides does a city on the ocean have during twenty-four hours?

7. How does the moon cause tides?

Problems to Solve

1. With a light, a large ball, and a small one show how eclipses of the sun and moon happen. You may use your head instead of a large ball to represent the earth.

2. The new moon, first quarter, full moon, and last quarter are known as the *phases* of the moon. At which phase of the moon does an eclipse of the moon occur?

3. At which phase of the moon does an eclipse of the sun take place?

4. The sun helps the moon make an unusually high tide during two phases of the moon. Which phases are these? Why?

5. Some people say moonlight is really sunlight. Is this true? Explain.

6. The moon always turns the same side toward the earth. Does it always keep the same side toward the sun? Explain.

7. You can make a scale model that shows the earth and moon and the distance between them. Use a ball two or three inches in diameter for the earth. Then calculate how large the "moon" should be and make it from clay or some other material that you can cut or mold to size. Calculate how far apart the balls should be and fasten them on a long board with nails. This model will help you solve Problem 8.

8. Can you think or find out why there is not an eclipse of the moon each month when the moon is on the opposite side of the earth from the sun?

9. On the scale you used in Problem 7 how far away and how large should the sun be?

HOW WAS OUR SOLAR SYSTEM MADE? No one knows, and probably no one ever will know, just how the earth and the other members of our solar system were made. It happened, of course, hundreds of millions of years before there was such a creature as man. While we cannot actually know what happened, we can figure out what might have happened. Scientists have collected many facts about the different members of the solar system. They have also observed many of the other heavenly bodies. With these facts as a starting-point, they have thought out ways of explaining what they have seen. Such an explanation is said to be an *hypothesis*.

An hypothesis is the best solution that we can think of for a problem at any given time. It cannot be proved to be true, but it gives the best explanation for the facts that we know. Sometimes, as new facts are discovered, they, too, can be explained by the hypothesis. At other times they cannot. Then the hypothesis must be changed to fit the new facts. When an explanation is called an hypothesis, you must remember that it is only the scientists' best estimate. It may be true, or it may not be true.

The best explanation that we have today for the way our solar system was made is called the *Planetesimal Hypothesis.*

Let us see, first, what facts our hypothesis must explain. We want to know how the planets were formed and why they keep circling around the sun in the same directions. Let us see how these problems are explained by the hypothesis.

Scientists believe that several billion years ago our sun had no planets circling around it. It was very much like our present sun except that it was larger. As it was journeying across the heavens, another star passed near it. Now, you have already learned that every object pulls on every other object. Therefore, our sun and the other star pulled on each other. The result was that great masses of material were torn away from the sun. Material may have been pulled out of the other star, too.

As the star passed on its way, it set the masses of gas from the sun whirling swiftly in great circles around the sun. This whirling motion kept the masses of gas from falling back into the sun. You have produced an effect like this when you have tied a string to a small bucket of water and whirled it around rapidly. The whirling movement threw the bucket out from the center. The pull of the string kept the bucket from flying out into space. In a similar way the pull of the sun kept the gaseous materials from flying out into space, and the whirling motion kept them from falling back into the sun.

The gaseous materials that had been torn away from the sun cooled off and changed into many solid bodies. These solid bodies have been given the name *planetesimals.* One of these bodies became our earth. When it was first

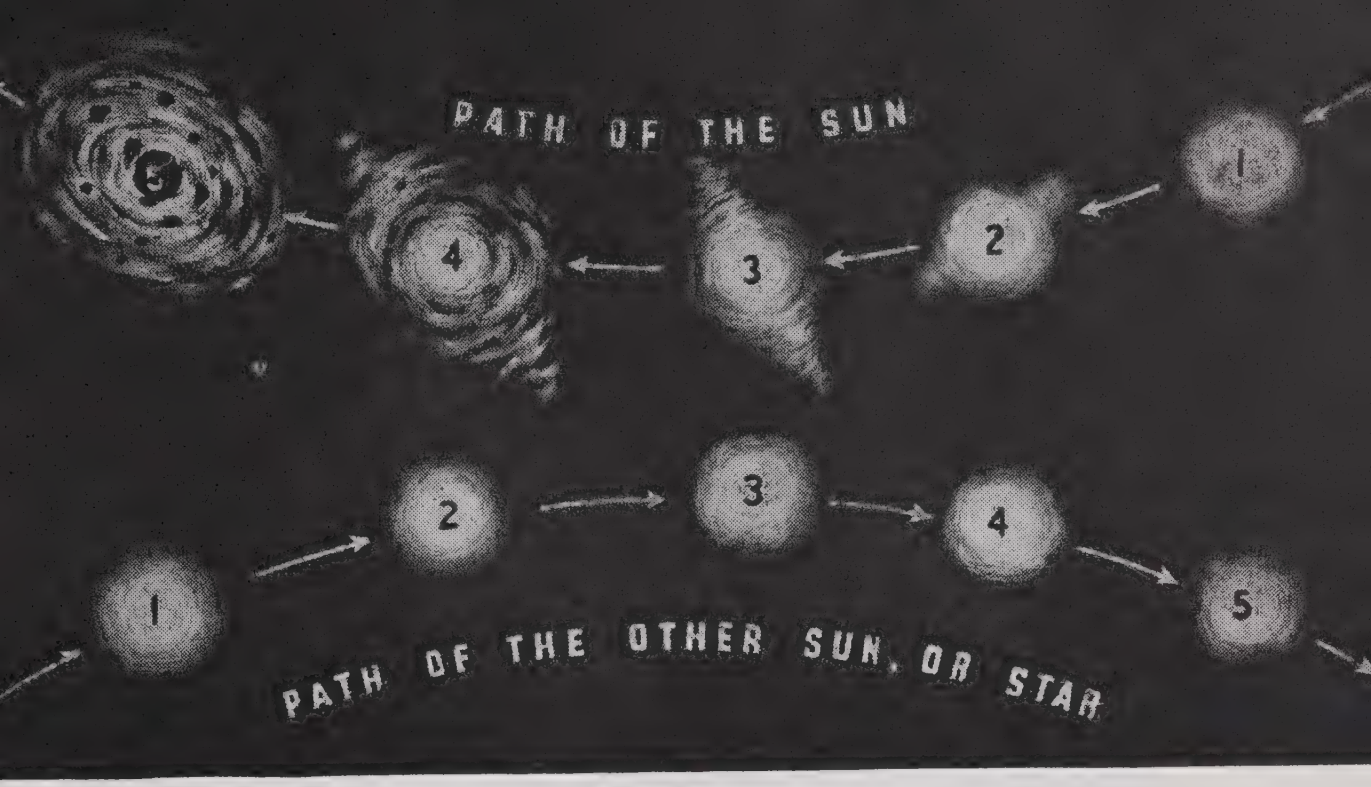

FIG. 26. The formation of the solar system is explained by this diagram. As our sun and the other star came close together, bulges were formed upon opposite sides of the sun as in 2. When the bodies came closest together, as in 3, great streamers of gas were pulled from the sun. Then the sun was left with masses of gas revolving about it, as in 4. Finally, as you see in 5, these revolving masses of gas became solid bodies that continued to revolve about the sun.

formed, it was probably only about one-tenth as large as it is now. As the earth journeyed around the sun, it passed near many of the smaller planetesimals, which were attracted to it. These, too, then became part of the earth. For millions of years this continued, and slowly the earth was built up to its present size.

In some way another body was formed near the earth. This was the moon. The moon never grew so large as the earth. The pull of the earth and the moon on each other caused the moon to circle around the earth. In a similar way the other planets and their moons were formed.

The hypothesis that you have just read is, of course, very much more complicated. This book can give you only the general idea of what scientists believe. As time

goes on and new evidence is found, the Planetesimal Hypothesis may be changed. It is, however, the best explanation that we now have.

Self-Testing Exercises

1. Tell in your own words how the Planetesimal Hypothesis explains the formation of the planets from the sun and the circling of the planets around the sun.
2. Explain how gravity helped the earth to increase in size.
3. What is the difference between an hypothesis and a fact?

Problem 3:
WHAT IS THE NATURE OF THE UNIVERSE?

HOW LARGE IS THE UNIVERSE? We have learned that the sun is a star. It has a family of planets, moons, and comets circling about it. All the other stars, or suns, are so far away in space that they look like points of light. Many of these distant suns may have their own families of heavenly bodies traveling about them. When we wish to talk about all the stars out in space, with all the other heavenly bodies, we speak of the *universe*. That is, the universe is everything that exists in space.

To us, who live on the earth, it seems that the earth must be a very important body. Of course, it is important to us, but is it a really important part of the entire universe? To answer this question we shall need to find out more about the universe.

You already know that the sun is so large that it would hold about a million earths. As compared with other stars, however, our sun is only medium-sized. Betelgeuse, one of the large stars, would hold about 27,000,000 suns and about 27,000,000,000,000 (twenty-seven trillion) earths. So far as size goes, you can see that the earth is a very unimportant, tiny body.

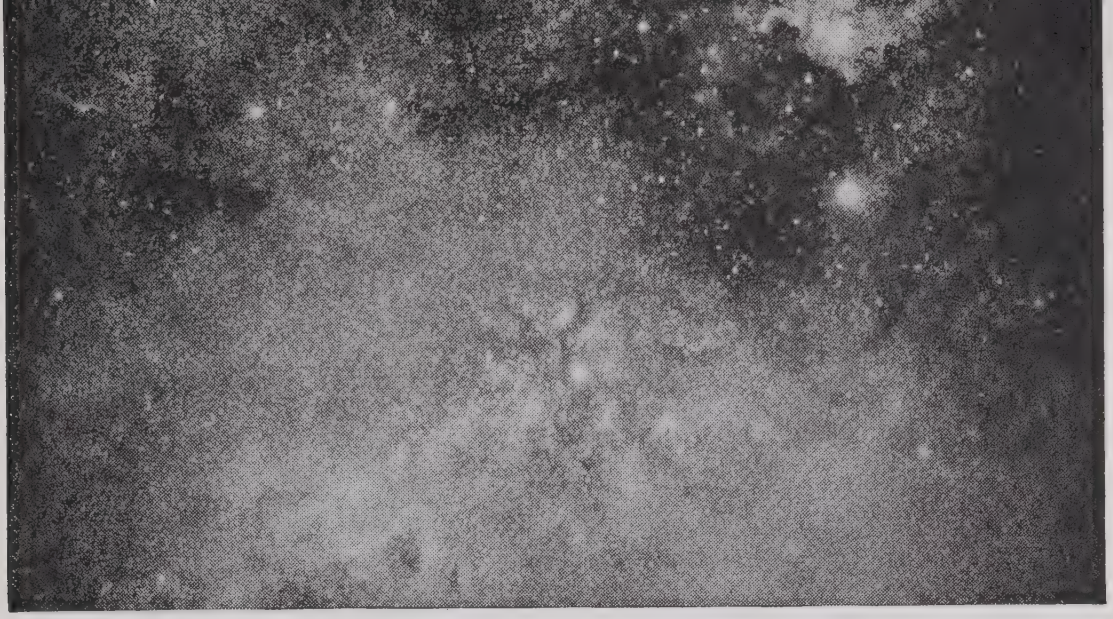

FIG. 27. Have you ever looked up into the *Milky Way* and wondered what it really is? The first observation with telescopes astonished astronomers by showing them that the Milky Way is made up of myriads of stars. In other parts of the sky not nearly so many stars can be seen.

When you look into the skies on a dark night, you can see fewer than 5000 stars with your naked eye. But with our most powerful telescope, at Mount Wilson, California, about fifteen hundred million stars can be seen. This number, scientists believe, is only a small fraction of the number of stars in the heavens. Such a number is, of course, so large that we cannot even imagine it.

When you travel on earth, a thousand miles is a fairly long trip. If you were to travel through the universe, a trip of a thousand miles would get you nowhere. Distances are so great in the universe that instead of using the mile as a measure of distance, the astronomer uses a *light year*. A light year is the distance that light travels in one year. Light travels at the rate of 186,000 miles a second. To find out how large a light year is, you must first multiply $186{,}000 \times 60 \times 60 \times 24$. This will give you the distance light travels in one day. Then you must multiply by $365\frac{1}{4}$ (the number of days in a year). If you multiply these numbers, you will find that light travels about 5,869,713,600,000 miles in a year.

FIG. 28. This glowing disk, called the Great Nebula of Andromeda, is made up of tens of thousands of millions of suns. It is 800,000 light years away from the earth. If you traveled as fast as light straight out into space without stopping, it would take you nearly a million years to reach this nebula.

The nearest star to us (except the sun) is 4.27 light years away. How many miles away would this be? The North Star is about forty light years away. Astronomers have seen some clusters of stars that are a million light years away. When you see how far away these stars are, you can understand why the astronomer does not use the mile as a unit of measurement. Here again the numbers that represent distances in the universe are so great that we cannot even imagine how enormous the universe really is.

WHAT IS THE SHAPE OF OUR GALAXY? As you look at the heavens, the stars seem to be scattered across the sky in great confusion. But that is not true. As men have learned more about the universe, they have found that the heavenly bodies have an orderly arrangement. They have also learned that the vast spaces out beyond the earth are not crowded with heavenly bodies even though they may seem to be. Space is really very empty

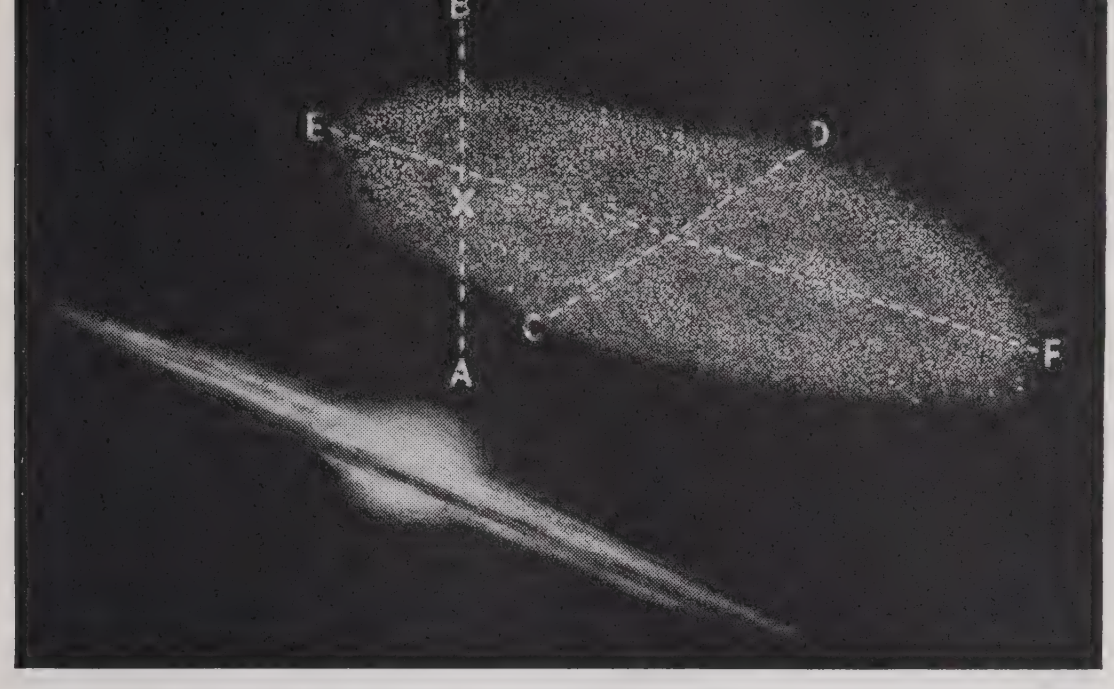

FIG. 29. The diagram at the top shows a slanting view of our galaxy as we imagine it would appear if we could look down upon it. The diagram at the bottom shows how scientists believe the galaxy would appear if we could look at it edgewise. The center of it is much thicker than the edges.

when we consider how vast the distances are between the heavenly bodies.

Astronomers believe that the sun, including the solar system and all the stars that we see at night, are members of a great star group, or *galaxy*. Our own galaxy seems to have a flat, disk-like shape, somewhat like a watch. This galaxy is much wider than it is thick (Figure 29). The solar system is located in this group of stars near the place marked X in Figure 29.

When you look out into the heavens at night toward point A or point B, you see comparatively few stars sprinkled over the skies. But when you look toward points C, D, E, or F, you are looking toward the farthest edges of the galaxy. Therefore you see many more stars when you look into these parts of the heavens. These stars appear as a band of light across the sky. We call this band of light the *Milky Way*.

However, you must not get the idea that the stars in the Milky Way are crowded as close together as they

FIG 30. This spiral nebula is millions of miles in diameter and about one million light-years away from the earth. Scientists believe that it is traveling away from our galaxy at a terrific speed.

appear to be. On the contrary, the stars are very far apart. They merely appear to be close together when we look at them because we are looking through such a great number of them.

Now the question arises, Does our galaxy contain all of the stars that exist? Astronomers think not. By means of very high-powered telescopes they have discovered about two million irregular-shaped, glowing masses of material called *nebulae* (singular, *nebula*). These nebulae, far outside of our own galaxy, are believed to be other galaxies of stars. A few of the nebulae seem to be masses of glowing gas that may be developing into clusters of stars.

If we stop to think that probably each of these countless nebulae contains as many stars as our own galaxy contains, we are staggered by the immense size of the universe. And when we remember that these millions of heavenly bodies are hundreds of thousands and even millions of miles apart, it is quite beyond our powers of imagination to realize just how large all of space is.

FIG. 31. In earlier times men grouped the stars into constellations or outline pictures of men, animals, weapons, and so on. About each of these pictures they told an interesting story.

HOW CAN WE LEARN TO NAME THE STARS? For many centuries people have enjoyed looking into the heavens upon dark nights and finding the stars that they know. Many of the brighter stars were well known to the ancients. The beauty of the great dog star, Sirius, filled the early Egyptians with awe, and Job, in the Bible, spoke of the star Arcturus. Long ago, lone shepherds watching their flocks at night imagined they saw pictures made in the skies by different groups of stars. They gave the names of animals, kings, queens, and their gods to these star pictures. Today we still find these sky pictures, and we still use the names that were given them long ago. Such groups of stars are called *constellations*.

The stars appear to rise and set just as the sun and moon do, but this is because the earth itself is turning. However, if you watch the northern heavens at night, you will discover that many of the stars do not "set." One star, the North Star, appears to stand still while the other stars seem to move around it in circles. The North Star

FIG. 32. The map shows the constellations that circle around the North Star night after night.

seems to stand still because it is almost exactly above the North Pole of the earth.

You are probably familiar with the Big Dipper (Ursa Major) and the Little Dipper (Ursa Minor). The two end stars in the bowl of the Big Dipper will help you find the North Star and the Little Dipper. On some dark, clear night try to find the constellations shown in Figure 32. Cepheus, Cassiopeia, and Draco, the dragon, are other northern constellations that can be seen almost any clear night.

Almost anyone can learn to locate some of the more prominent constellations. As the earth moves around the sun during the year, the dark side of the earth is turned toward different parts of the heavens and finally comes back to the same part again. For this reason some constellations that can be seen during one season are invisible during another season. Figures 33 and 34 show maps of the eastern sky in autumn and in spring.

FIG. 33. When you look toward the eastern sky at eight o'clock in the evening in October, these are the constellations that you should be able to find.

Some of the constellations and stars shown on the autumn map are: Taurus, the bull, with the red star Aldebaran; Auriga, with the gold star Capella; Cetus, the sea-monster; Aries, the ram; Pisces, the fish; Cassiopeia, the queen in her chair; Andromeda, the daughter of Cassiopeia; Perseus, who rescued Andromeda; and Pegasus, the winged horse, which has no very bright stars in it. Locate these constellations on the sky map (Figure 33) and then try to find them in the night skies during the autumn.

Some of the constellations of the spring skies are: Boötes, the plowman, with the yellow-orange star Arcturus; Leo, the lion, with the star Regulus; Virgo, with the white star Spica; Draco, the dragon; Hydra, the ser-

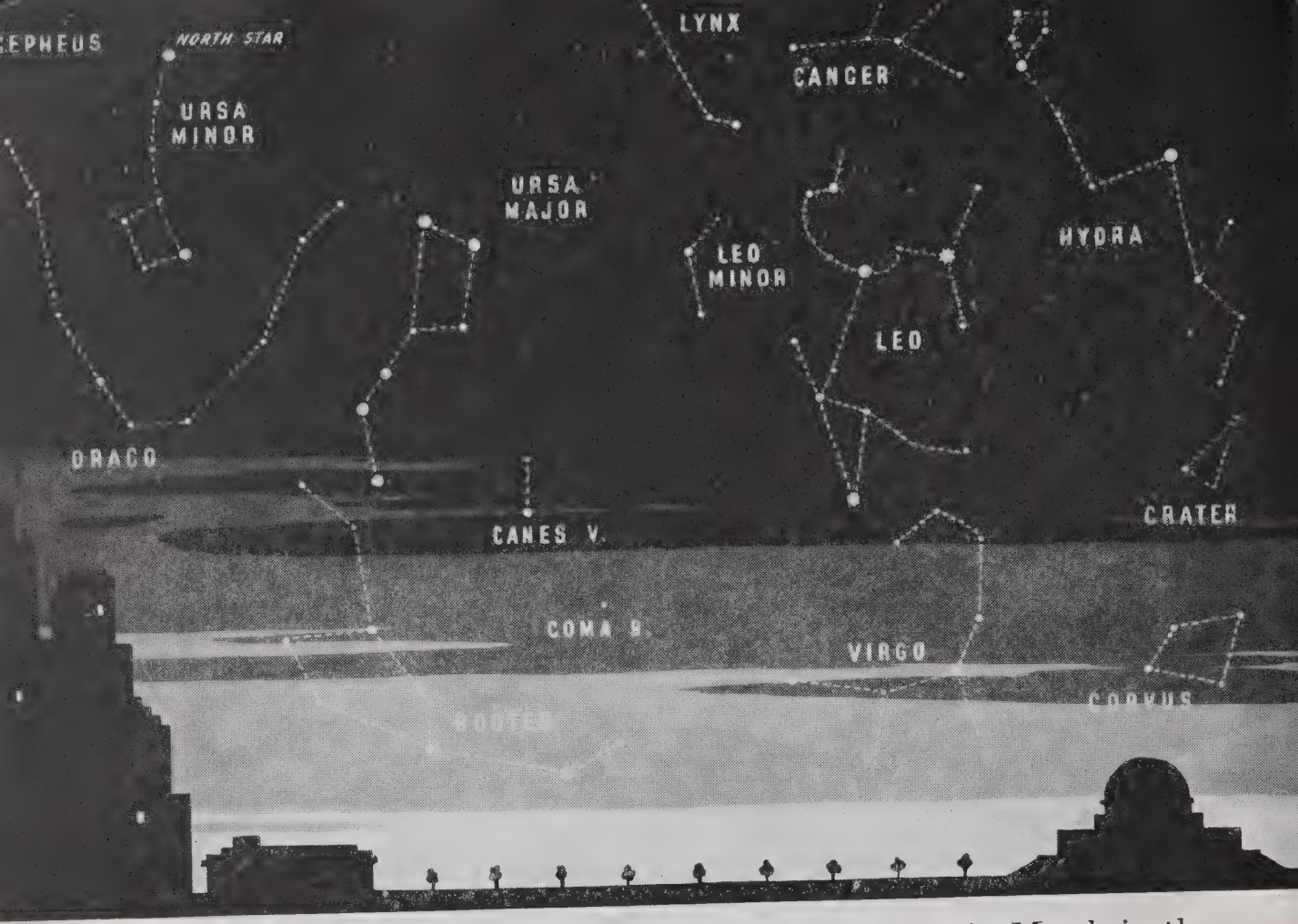

FIG. 34. These are the constellations you can see in March in the eastern sky at eight o'clock in the evening.

pent; Corvus, the crow; the Crater, the cup. Locate these constellations and stars on the spring sky map (Figure 34); then try to locate them for yourself in the night skies next spring.

Many of the constellations have interesting legends that have been told about them since ancient times. You can read these legends in books about the stars.

Self-Testing Exercises

1. Tell what the term *universe* means to you.
2. What is a constellation?
3. What is a light year? Why do astronomers use light years?
4. Why do the constellations of the northern skies seem to circle about the North Star?

5. Use the words listed to fill in the blanks below.

star(s)	*planets*	*galaxies*	*universe*
moons	*planetoids*	*comets*	

a) The universe is composed of .....

b) A galaxy is composed of .....

c) The solar system is composed of ....., ..., ..., ..., and .....

6. Why do we see different constellations in the skies at different times of the year?

7. Why does the Milky Way appear so light?

8. What is the shape of our own galaxy?

9. How long would it take an airplane flying at the rate of 200 miles an hour to reach the North Star? (See page 38.)

Problem 4:

HOW DO THE EARTH'S MOVEMENTS AFFECT US?

Is it hard for you to believe that you are living on a body that is moving faster than any airplane? The earth travels or revolves around the sun in one year at a speed of 66,000 miles an hour. It rotates on its axis at a speed of 1000 miles an hour at the equator. These things are hard to believe, yet careful measurements made by scientists with the help of their telescopes show that they are true. They also find that the earth's axis does not point straight "up and down" as the earth goes around the sun. It is tilted $23\frac{1}{2}$ degrees.

The two movements of the earth and the tilt of the axis explain many things. You already know why we have years. A year is the length of time the earth takes to go around the sun. Day and night are caused by the earth's turning on its axis, so that we are carried out into the light of the sun and then back into the earth's shadow each twenty-four hours. But why are the days longer in summer than they are in winter?

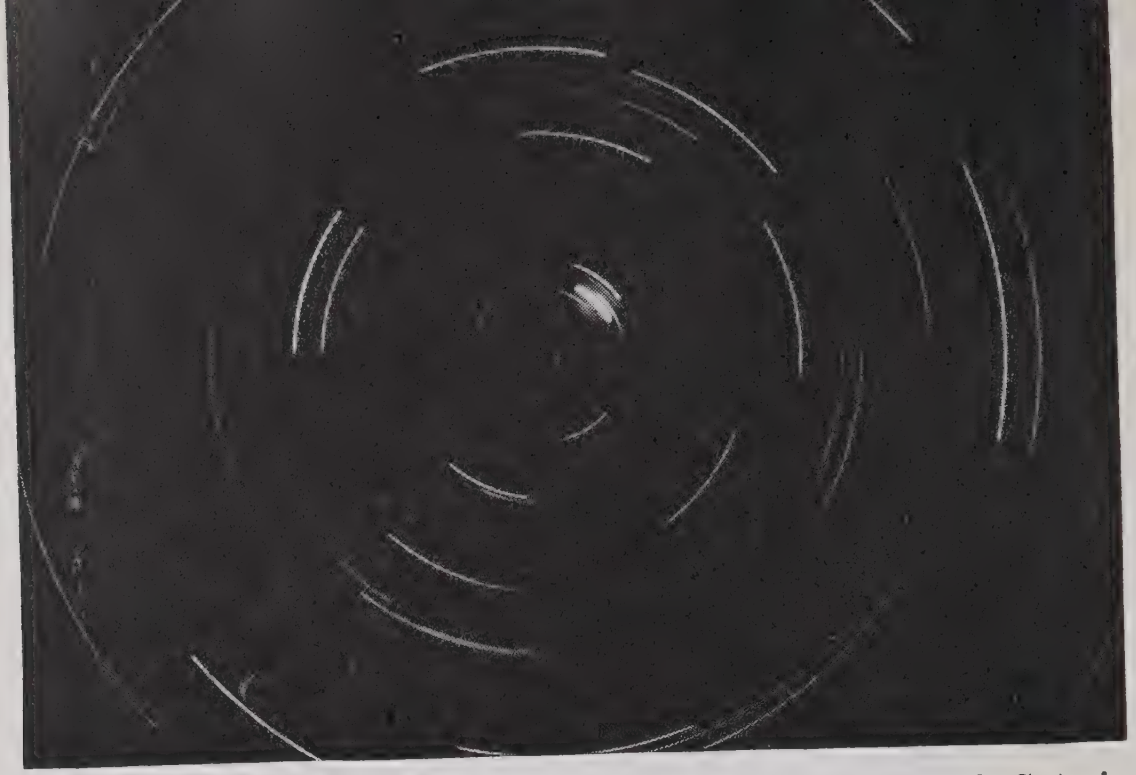

FIG. 35. This picture of the star trails around the North Star is another proof that the earth is rotating. When a camera is set for an hour's time exposure with the North Star in the center, a picture like this results. Since the stars are bodies like our own sun, they are not rotating; therefore, the earth must be moving.

WHY DO THE DAYS AND NIGHTS DIFFER IN LENGTH AT DIFFERENT TIMES OF THE YEAR? Everyone knows that the longest days in the year come near June 21, and the shortest days near December 21. About March 21 and September 21 the lengths of the days and nights are equal. Now let us see if we can understand why this change in the length of the day and night takes place.

EXPERIMENT 3. *Why Does the Length of the Days and Nights Change?* (*a*) Push a knitting needle or wire about six inches long through a tennis ball. The tennis ball is to represent the earth. Draw a circle around the ball to represent the equator. Draw another circle to show the latitude in which you live and place an X on it to represent your city. Make a stand for the ball, as shown in Figure 36.

Now draw a circle at least two feet in diameter upon a piece of wrapping paper. This represents the earth's path around the sun. Divide the circle into quarters, as shown in Figure 36. Write the dates of the beginnings of the four seasons. Turn the

paper so that the winter position is in the north, and set a lighted candle at the center of the circle.

Place the ball on the circle at the point marked autumn, with the needle (axis) in a perpendicular position. Observe that the light from the candle lights up the ball from pole to pole. Turn the ball on its axis. Does it still light up the ball from pole to pole? Now place the ball, in turn, at the points marked for each of the other seasons and rotate it. Does the candle always light up the ball from pole to pole? If the axis of the earth were straight up and down, would the length of the days and nights change?

b) Now place the ball at the autumn position (east of the candle), with its axis at an angle of about 23 degrees from the vertical line and pointing toward the north. (This angle can be measured with a protractor.) Rotate the ball on its axis. Does the candle light up the ball from pole to pole? Would the length of the days and nights be equal at the spot on the "earth" marked X?

c) Now place the ball in the winter position, with its axis still tilted toward the north. On the circle where you live measure with a piece of string the part of the ball that is lighted. Also measure the part of the ball that is dark. Will the days

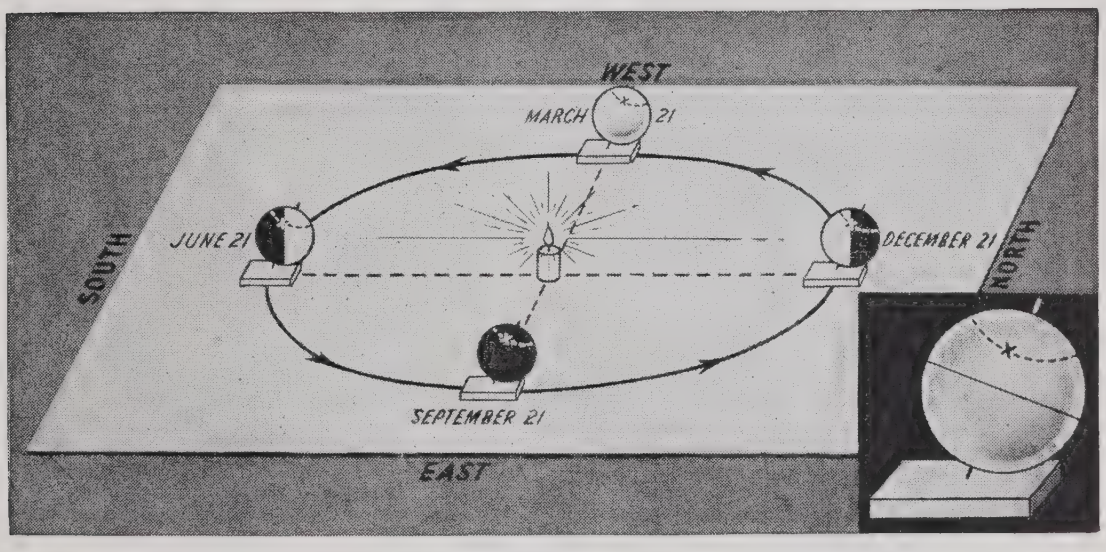

FIG. 36. Apparatus for Experiment 3

be longer, shorter, or the same length at this season of the year?

d) Move the ball to the spring position and repeat part *b* of the experiment. Will the length of the days and nights be equal?

e) Move the ball to the summer position and repeat part *c* of the experiment. Will the days be longer, shorter, or the same length in the summer?

Now let us see what this experiment shows. You found that the days and nights would be the same length all year round if the axis of the earth were perpendicular to the path it takes around the sun. But you know that the days and nights are not the same length all during the year.

When the earth's axis was tilted, you found that in autumn and spring the earth was lighted from pole to pole. When the earth rotated, the lengths of the days and nights were the same. In the winter, the lighted part of the earth where you live was smaller than the dark part. Therefore the days were shorter than the nights. In summer the lighted part of the earth where you live was larger than the dark part. Therefore the days were longer than the nights.

From this experiment you can see that the length of days and nights changes because of two facts: (1) the axis of the earth is tilted; (2) the earth moves around the sun.

Self-Testing Exercises

1. Why are the lengths of the days and nights the same about March 21 and September 21?

2. Why are the days shorter in winter than in summer?

3. State all the things you need to know to explain why the lengths of the days and nights change during the year.

Problems to Solve

1. Make a graph showing the lengths of days and nights for your locality, (*a*) on December 21, and (*b*) on June 21.

2. At Hammerfest, Norway, which is located at 71° N., the sun never sets from May 13 to July 8, and never rises from November 12 to January 23. See if you can explain why this is true.

WHY DO WE HAVE DIFFERENT TIME IN DIFFERENT PARTS OF OUR COUNTRY? If you have ever traveled across the United States, you discovered that at certain places you had to change your watch. If you travel east, you set your watch an hour faster at certain places. If you travel west, you set your watch an hour slower. Probably you have noticed that a radio program scheduled at nine o'clock in New York comes on the air at eight o'clock if you live in the central states, and at six o'clock if you live on the Pacific Coast. Do you know why all parts of our country do not have the same time?

As you watch the sun in the morning, it appears to rise in the east. Actually, of course, the earth is rotating from west to east, and as it turns farther and farther, the sun appears higher in the sky. The circumference of the earth is about 25,000 miles

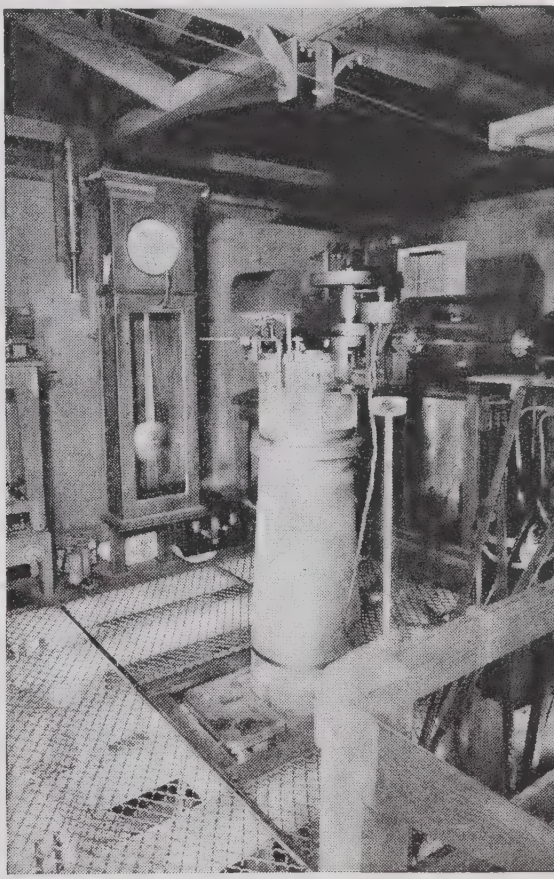

FIG. 37. The U. S. Weather Bureau gets time data by using the rotation of the earth, which is a regular movement, and a telescope. The telescope is set in a north and south line. The exact time when the sun appears in the telescope is noon. The time that elapses until the sun appears again is a day.

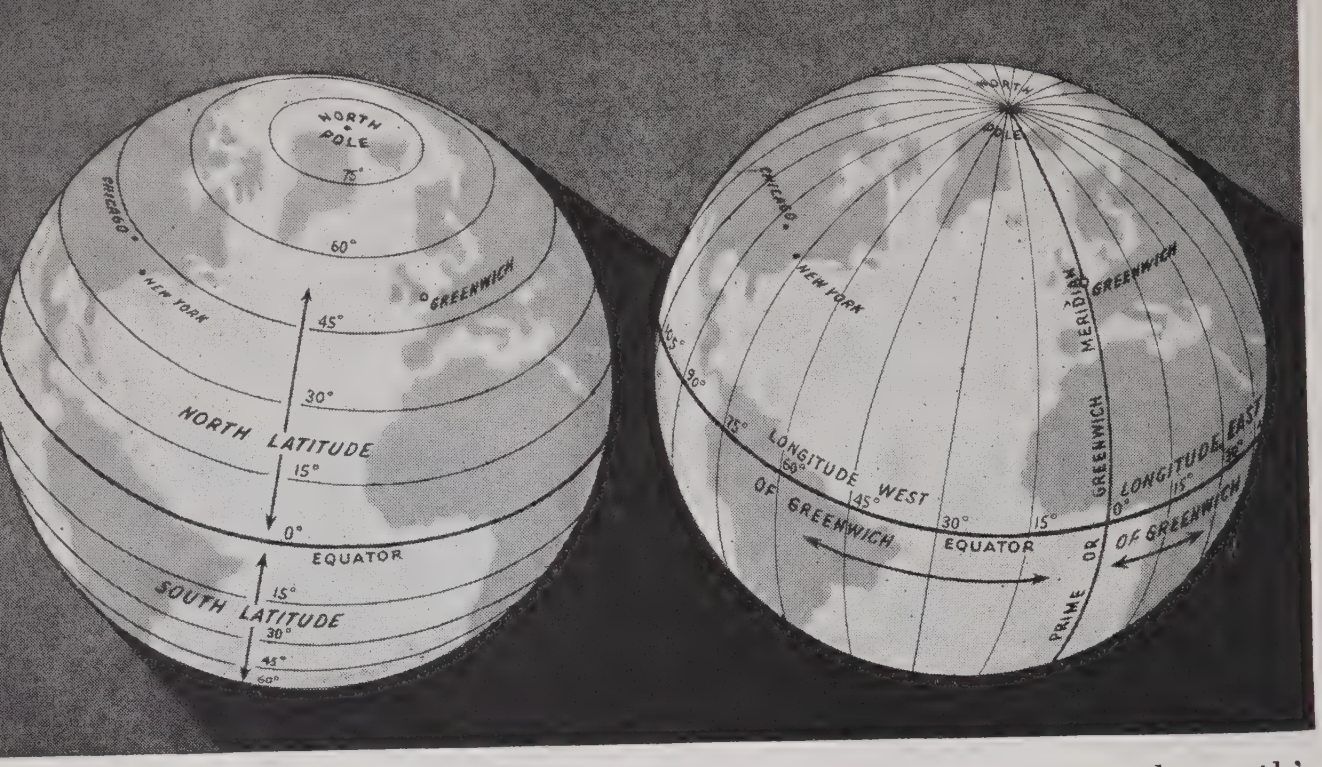

FIG. 38. This diagram shows how we locate places on the earth's surface by means of *latitude* and *longitude*. Latitude is measured in degrees north and south of the equator. Longitude is measured in degrees east or west of the *prime meridian*, which passes through Greenwich, England. What are the latitude and longitude of Chicago and New York?

at the equator. Since the earth turns once on its axis every twenty-four hours, you see that the earth is rotating at a speed of about 1000 miles an hour at the equator, or about 17 miles per minute. At the latitude of New York (40° N.) the earth is not so large around, and its speed of rotation is about twelve to thirteen miles a minute. This means of course that in a city about 800 miles west of New York the sun would rise an hour later. In between the two cities the sun would rise at about a minute later for each twelve or thirteen miles that the place was farther west of New York. Each place would thus have a different time by the sun.

It would, of course, be very confusing if each city had its own time. For this reason the government has adopted a *standard time* system. The sun reaches the eastern part of the United States first; so all places within one-half hour's time east and west of the 75th longitude line, or

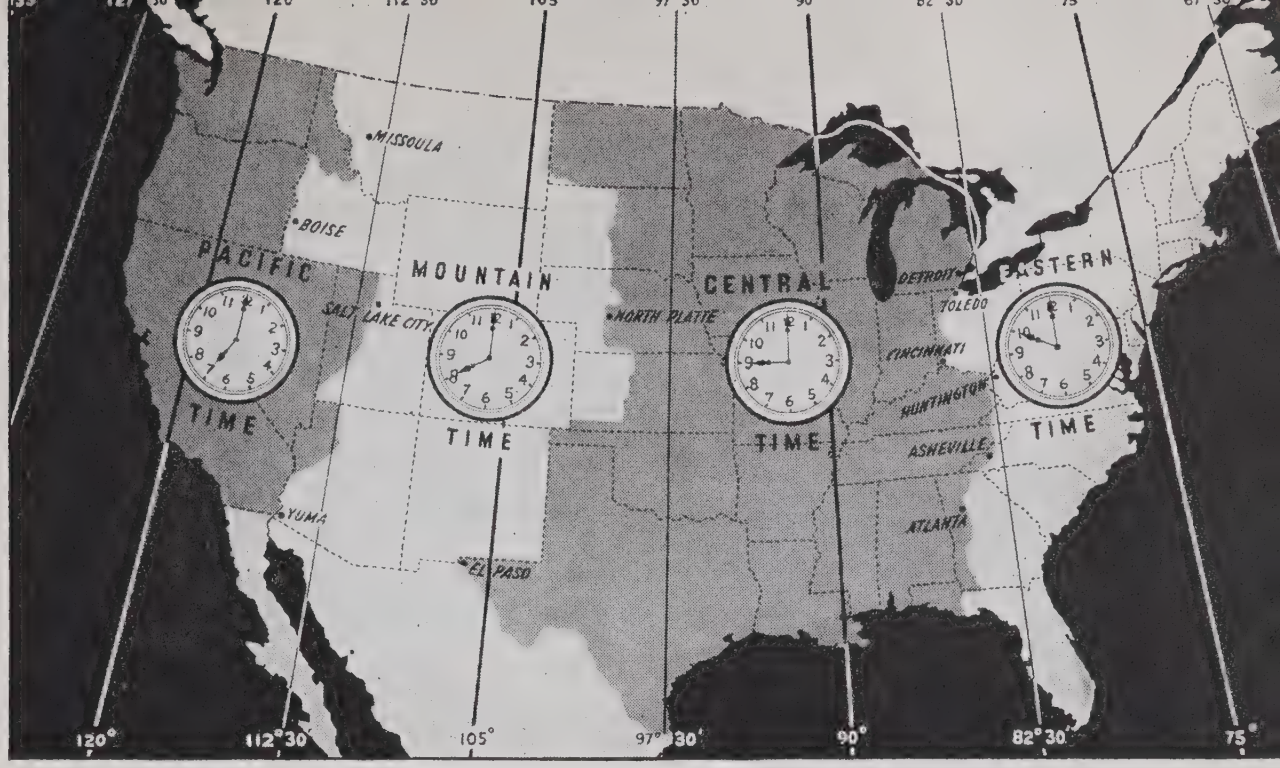

FIG. 39. The standard time belts in the United States. The boundaries of the different belts are irregular because it was found more convenient in operating the railroads to change time at certain stations.

meridian, have *Eastern Standard Time* (Figure 39). They are in the Eastern Time Belt. Similarly, places along the 90th meridian have *Central Standard Time;* those along the 105th meridian have *Mountain Standard Time;* and those along the 120th meridian have *Pacific Standard Time.*

People who travel long distances have to set their watches back an hour whenever they cross from one time belt to another in going from east to west. In going from west to east, they set their watches forward one hour when they pass from one time belt to another.

Self-Testing Exercises

1. Why do different places have different time by the sun?
2. What is the standard time system?
3. Why was the standard time system adopted in the United States?
4. How many time belts are there in the United States? In which one do you live?

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WHY DO WE HAVE SEASONS? If someone asked you why the days are warmer in summer than in winter, your first answer would probably be, "Because the days are longer in summer." Your answer would be partly correct, because the days are longer in summer than in winter, and the earth therefore receives more heat during the longer hours of sunlight.

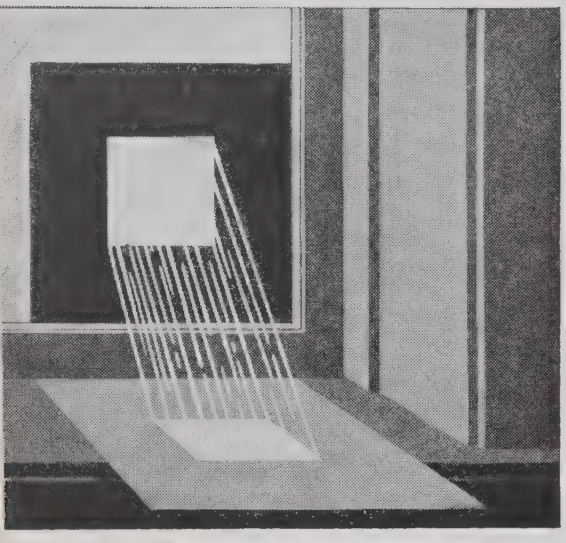


FIG. 40. Apparatus for Experiment 4

But this is not the only reason why summer days are warmer. There are other conditions that help make summer warmer than winter. The following experiments will help you to see some of the other conditions that cause the seasons.

EXPERIMENT 4. *How Does the Angle of the Sun's Rays Change from Day to Day?* Get a piece of cardboard to put on a window-pane in your schoolroom and cut a four-inch square from the center of it. Fix the cardboard over a window-pane where the sun will shine through the opening. Place a piece of paper upon a table-top or other flat surface in the spot of sunlight and draw the outline of the bright area (Figure 40). Write the date and exact time upon this sheet of paper.

Repeat the experiment again a week later. Be sure to do the experiment at exactly the same time of day and place the paper in the same position as before. Do the experiment several more times at intervals of a week.

Compare the shapes of the lighted areas. Do the shapes appear to be changing? Does the lighted spot get nearer to, or farther from, the window? From this experiment, can you say that the angle at which the sun's rays strike the earth changes from time to time?

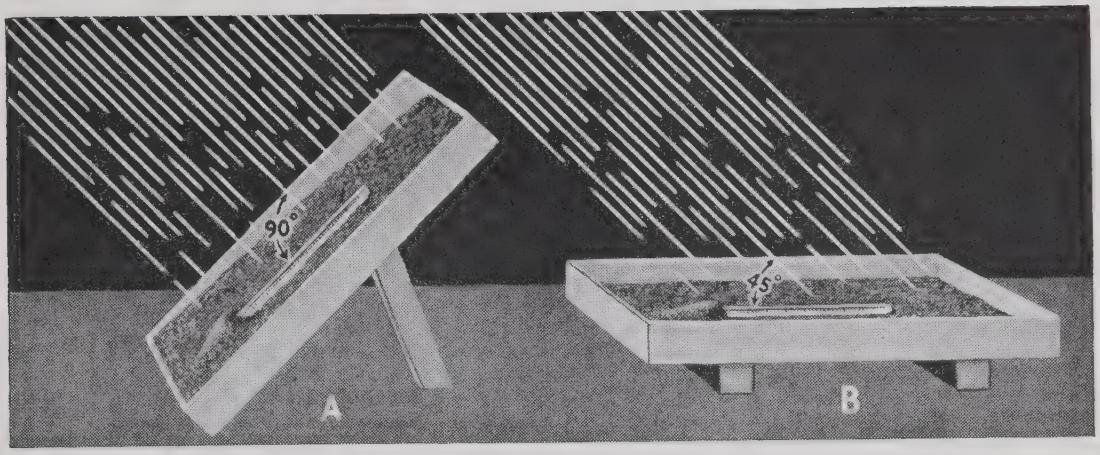


FIG. 41. Apparatus for Experiment 5

EXPERIMENT 5. *How Does the Angle of the Sun's Rays Affect the Amount of Heat the Earth Gets?* Fill two cardboard boxes with sand or dry soil as shown in Figure 41. Lay thermometers on the boxes with the bulbs buried in the sand.

Place one box, as shown in *A* of the figure, so that the sun's rays will fall upon it vertically, that is, at an angle of ninety degrees. Arrange the other box with sand and thermometer on two small blocks, as shown in *B* of the figure, so that the sun's rays will fall upon it at an angle of about forty-five degrees.

Allow the sunlight to shine upon both boxes for about twelve minutes. Record the temperature of the sand on both boards. Are direct or slanting rays of the sun hotter?

You have probably observed that the sun gets almost straight overhead at noon in summer. In winter, however, the sun at noon is scarcely half-way up to that point. From Experiment 3 you will remember that the upper half of the earth (where we live) is slanted toward the sun in summer. In winter the opposite is true: The axis of the upper half of the earth is slanted away from the sun. This slant of the earth's axis causes the sun's rays to strike the earth at different angles during different seasons of the year.

Vertical rays in summer, when the sun is almost directly overhead, give a greater amount of light and heat to the earth. Slanting rays in winter give less light and heat.

If you compared the amounts of light and heat received by a square foot of the earth during the same hour in winter and summer, say from one to two o'clock in the afternoon of an average day, you would find that the amount of heat and light received would be much greater in summer. You learned from your experiments that the more nearly vertical the sun's rays are when they strike the earth's surface, the smaller amount of surface they cover. When the same amount of radiant energy is spread over a smaller surface, the amount of heat received by that surface will be greater.

As you have learned, in winter the sun's rays strike the earth at a much greater angle than in summer. This affects the temperature of the earth in another way. When the sun's rays strike almost vertically, they have much less atmosphere to pass through than when they strike the earth at a greater angle (Figure 42). Dust particles or particles of other substances in the air help to stop or scatter the sun's rays. So, when these rays have a smaller amount of atmosphere to pass through, the earth receives more heat.

Let us summarize the conditions that cause summer and winter:

(1) Days are longer in summer than in winter; therefore the earth has more hours of sunshine to heat it.

(2) Because the earth's axis is inclined toward the sun in summer, the sun's rays strike the earth more nearly vertically; therefore they give more heat to the earth.

(3) In summer the sun's rays pass through less at-

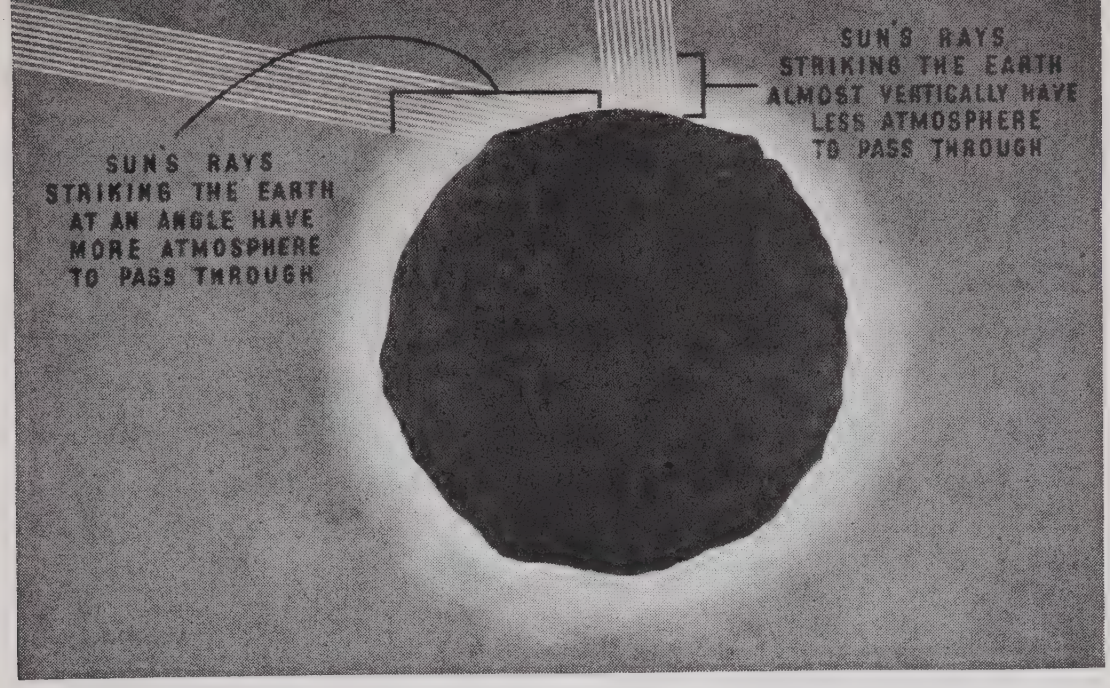


FIG. 42. A comparison of the amount of atmosphere the sun's rays pass through in summer and in winter.

mosphere than in winter; therefore they lose less of their heat. Each of these conditions helps to make summer warmer than winter.

Self-Testing Exercises

1. Close your book and give three reasons why summer is warmer than winter.

2. Close your book and draw a diagram that shows why the sun's rays shine more nearly straight down on you in the summer time. First, draw a circle to represent the earth. Add marks for the North and South Poles. Put an X on the circumference about where you live. Then add the sun and its rays.

Problems to Solve

1. Use a diagram like the one for Self-Testing Exercise 2 to show why people on the southern half of the earth have warm weather at Christmas time.

2. Do people who live at the equator have summer and winter as we do? Explain.

3. How would our seasons be different if the axis of the earth were not inclined?

Problem 5:

HOW DO ASTRONOMERS LEARN ABOUT THE HEAVENLY BODIES?

Scientists who work with things on the earth can handle the materials they are studying. They can feel and weigh and measure them. They can put samples into test-tubes and find what elements and compounds are present. But astronomers cannot do that. All they have to work with is the light that comes from the heavenly bodies.

Yet astronomers are able to tell us that what appears to be a mere point of light in the night sky is really two great suns fifty light-years away, revolving around each other and at the same time traveling away from the earth at a rate of twenty-five miles a second. The astronomers can also tell us what elements these suns and other suns are made of. How can so much be learned from such a tiny bit of light?

In the time of the Greeks the only instruments astronomers had were queer-looking devices for sighting the stars and measuring the angles at which they were seen. These instruments could be used to measure the angles of the stars in relation to the earth because the light from a star comes in a straight line from the star to the observer on the earth.

These were the only kinds of instruments used by astronomers until Galileo began to use the telescope about 330 years ago. Today practically every observation of a heavenly body is made through a telescope of some kind. Cameras, instruments for measuring angles, and instruments for studying the light in special ways are attached to the telescopes. Often microscopes and very accurate measuring instruments are used to study the photographs made with the help of telescopes.

HOW DO TELESCOPES HELP ASTRONOMERS? Telescopes do two things that are helpful in studying the stars. They magnify such objects as the moon or a planet so that these heavenly bodies appear to be larger and nearer than when we look at them without an instrument. To make a magnified moon bright enough to study with care, the telescope must also gather a great deal more light than can fall on the pupil of a person's unaided eye. However, even the most powerful telescopes show all stars as points of light. The only thing a telescope can do is to make them seem brighter by gathering a great deal of light and concentrating it at one point.

Telescopes are made with curved disks of glass called *lenses*. Since a lens works by bending, or *refracting*, the light rays, this kind of telescope is known as a *refracting telescope*.

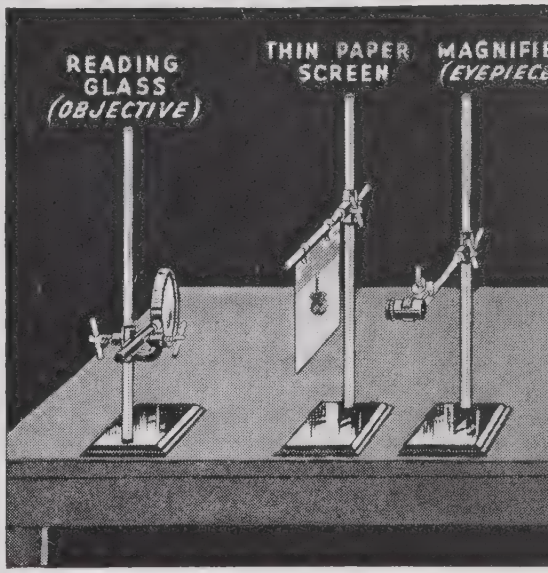


FIG. 43. Apparatus for Experiment 6

EXPERIMENT 6. *How Does a Refracting Telescope Work?* Arrange a reading glass, a paper "screen," and a magnifier before a window as shown in Figure 43. A large cardboard around the reading glass will help shut out the light you do not need. Other windows should have the shades drawn.

Now move the paper screen slowly back and forth until you see on it a distinct "picture," or *image*, of some distant object, such as a chimney or a tree. This image will always be upside down. Next look through the magnifier and move it until the paper screen with the image on it is magnified and shows clearly. Now remove the screen and look through the magnifier. The distant object should be visible and should appear closer than it does without the lenses.

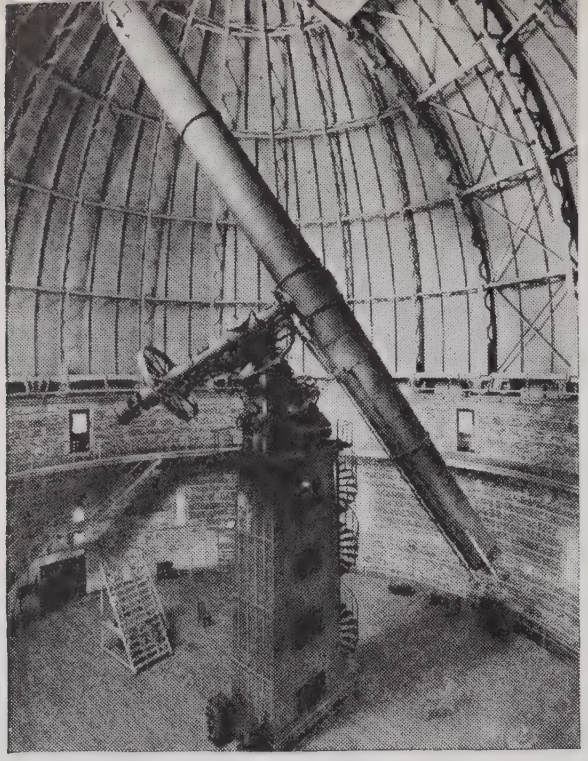


FIG. 44. The sixty-foot telescope at Yerkes Observatory, Williams Bay, Wisconsin, is the largest refracting telescope in the world. The lens at the upper end is forty inches in diameter.

Two ordinary lenses arranged as in Figure 45 show how all refracting telescopes work. A large lens, called the *objective*, forms an *image*, or picture, of what is to be seen. Then the smaller lens, or eyepiece, magnifies the image for the eye of the observer. As you discovered, if you did the experiment, the image does not have to fall on a screen to be seen through the eyepiece.

In such a crude telescope as the one that has just been described, the objects do not show very clearly, and there are false colors around them. To get sharp images and to avoid false colors, good telescopes have very carefully shaped lenses made of two kinds of glass fastened together.

As you probably know, we see objects because they

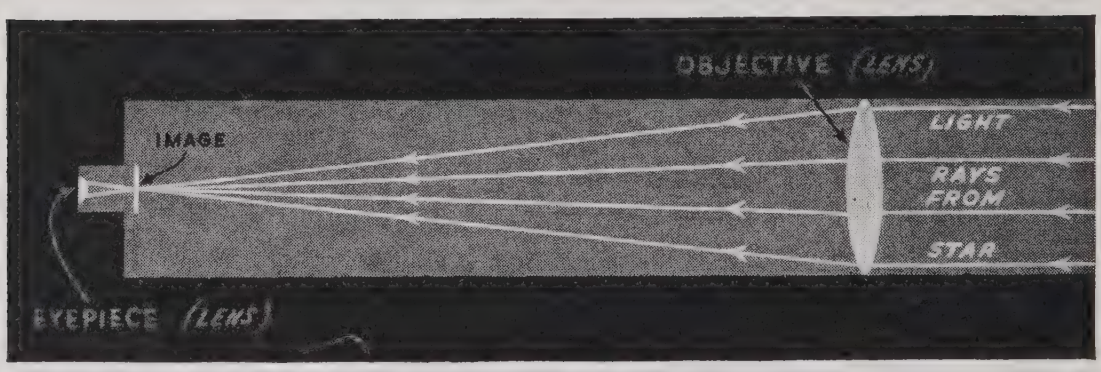


FIG. 45. This diagram shows the essential parts of a refracting telescope and how the rays of light from the stars travel through the telescope to the eye of the observer.

send light to our eyes. The farther away an object is, the less light our eyes receive from it. When we see a star, light from the star passes through the pupil of the eye. A lens inside the eye bends it, so that it all falls at one point in the back of the eye. Naturally, only a little light can be received because the pupil is so small. Many stars are so far away that our eyes do not receive enough light from them to enable us to see them.

FIG. 46. The large reflecting telescope at Mount Wilson Observatory has a frame instead of a long tube to hold the mirrors and the eyepiece. The part that holds the 100-inch mirror can be seen at the lower end of the frame.

The objective lens of a telescope is, of course, much larger than the pupil of the human eye. Therefore much more light from a star can be gathered by the lens than by the eye. It is somewhat like the amount of light that comes into a room through a large window as compared with the amount of light that would come in through a small hole in the curtain.

The objective lens also bends the light rays that strike it so that a great deal of light is concentrated in a small space. Thus, it is possible to see objects that could not be seen with the naked eye. A one-inch lens, for example, gathers twenty-five times as much light as a person's eye and brings these rays together in a small space. This makes it possible to see 220,000 stars that cannot be seen with the eye alone.

In a reflecting telescope no large lens is used. The light from the star falls upon a large mirror. The surface of this mirror is *concave*, that is, it is hollowed out. When light from a star strikes such a mirror, the rays that are reflected back all come together at one point. A small, flat mirror (Figure 47) is placed below the point where the rays come together. This mirror reflects the light out to one side where an eyepiece can be used to look at the image. Large mirrors are much easier to make than large lenses. For this reason our most powerful telescopes are "reflectors."

The largest reflecting telescope now in use has a mirror 100 inches (more than eight feet) in diameter. This is in the Mount Wilson Observatory in California. A glass mirror 200 inches ($16\frac{2}{3}$ feet) in diameter was made in 1935 and is being prepared for use. It will be placed in a telescope in a new observatory on Mount Palomar in California.

Astronomers use a telescope to take pictures by removing the eyepiece and putting a photographic plate where the image is made by the large lens. If the image is kept in exactly the same place for a long time, the photograph that is made shows many stars that cannot be seen by

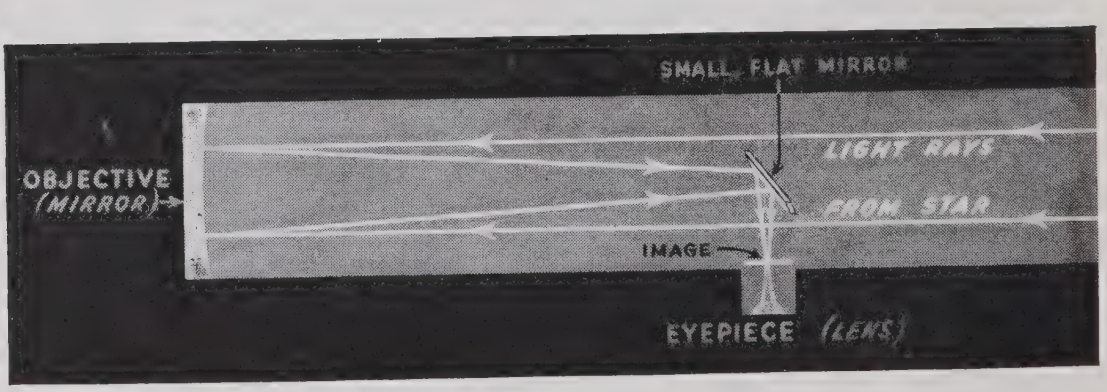


FIG. 47. This diagram shows the essential parts of a reflecting telescope and how they gather light.

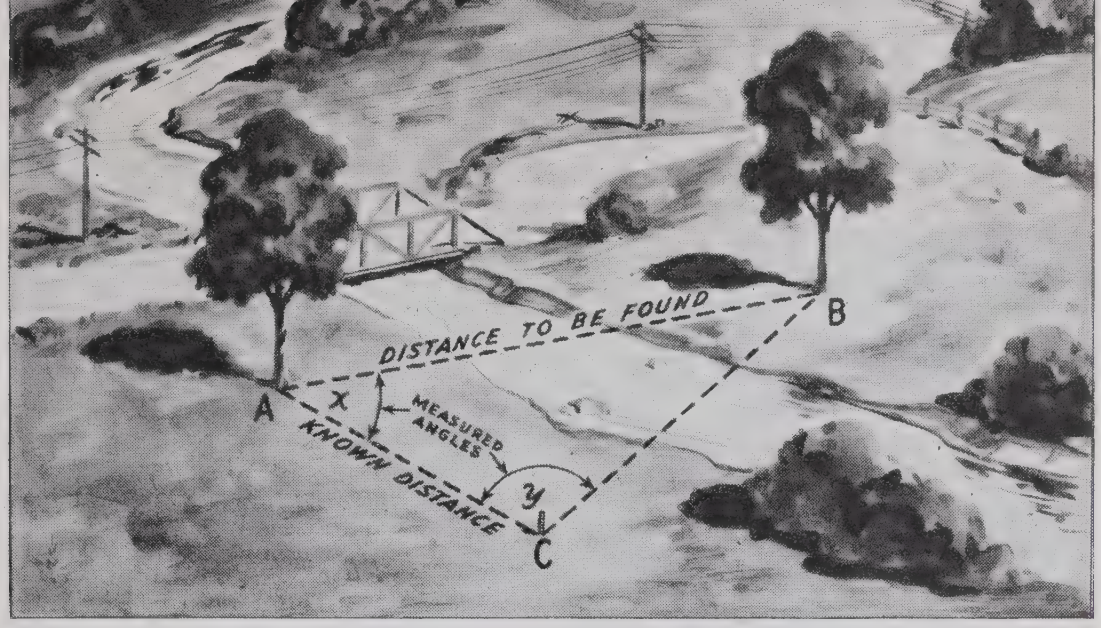


FIG. 48. A surveyor can find the distance between two places by measuring angles and solving a mathematical problem.

looking through the telescope. Some star pictures have been exposed night after night until the starlight has shone on the plates for twenty-five hours. Two- and three-hour exposures are quite common.

HOW DO ASTRONOMERS MEASURE DISTANCES? We have already learned that the early astronomers invented instruments for sighting stars and measuring their positions. Methods of measuring angles are now so accurate that an astronomer in Chicago, watching a light as far away as New York, could measure how far it is moved sidewise and not make a mistake of more than three-fourths of an inch.

To measure distances, astronomers follow the plan used by surveyors when they measured the distance to some object on the opposite side of a river. If the surveyor wishes to know how far tree B is from tree A (Figure 48), he sets a stake at C. With his instruments he measures the angle at x, the angle at y, and the distance from tree A to the stake, C. Then by solving a mathematical problem he can find the distance between A and B. In a similar way, two astronomers located at different points may sight a planet at the same time. Then, by knowing the

position of the planet as seen from each telescope and the distance between the telescopes, they can calculate the distance to the planet.

When astronomers began to measure the distances to stars, they had to make a change in their method. Most stars are so far away that no difference in the angle can be found from different points on the earth's surface. Astronomers found, however, that if they sight these stars at one time and then sight them again six months later, a difference in the angle is obtained.

FIG. 49. Two astronomers located at different places on the earth can find the distance to the moon by measuring the angles at which they see the moon and by knowing the distance between the two places.

During the six months the earth travels half-way around the sun. It is then 186,000,000 miles away from the place it was six months before. This gives the astronomers a triangle with one side 186,000,000 miles long. They have found that by this method the distance to stars that are not more than 300 light-years from the earth (about 1,761,000,000,000,000 miles) can be measured fairly accurately.

Most stars are farther away than 300 light-years. They are so far away that they seem to stand still as the earth swings around the sun. To estimate the distance to these

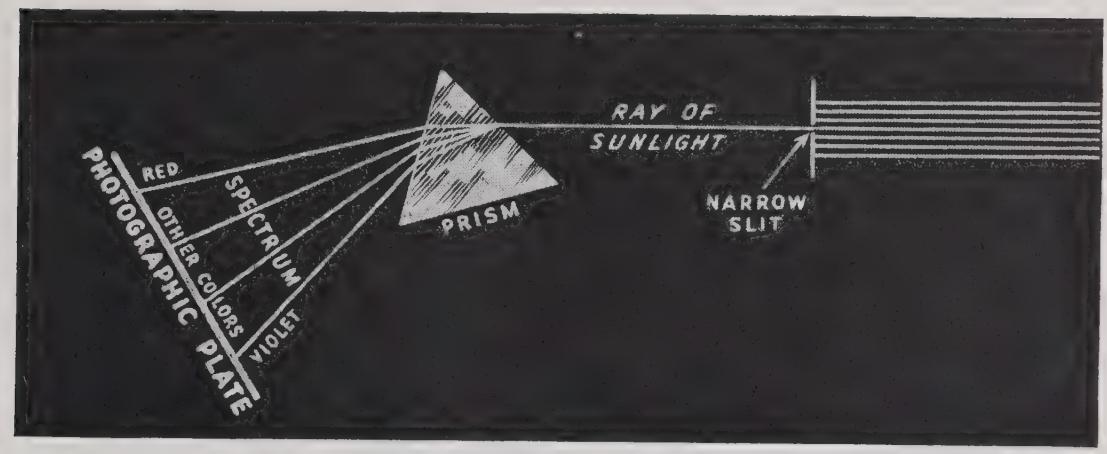


FIG. 50. In a spectrograph a prism bends each color in a ray of light a different amount and thus separates it from the other colors. In real spectrographs several lenses are used to make the lines in the spectrum distinct.

farther stars and to measure the diameters of stars, astronomers must use methods that we cannot explain to you now.

HOW CAN ASTRONOMERS TELL WHAT ELEMENTS ARE IN THE SUN AND THE STARS? Have you ever seen a ray of sunlight shining through a triangular bar of glass or through the corner of a rectangular aquarium? If so, you have seen how the white light of the sun is spread out into a band of rainbow colors. This band of colors is called a *spectrum*. It shows that sunlight is really a mixture of many different colors of light.

The triangular piece of glass used to spread out a ray of light in this way is one kind of *prism*. By sending a ray of light through a narrow slit, a prism, and some lenses, scientists can make a very perfect separation of all the colors of light in a mixture. An instrument that separates the colors of light in this way is called a *spectroscope* (or *spectrograph*, if it takes a picture of the spectrum). Astronomers use spectroscopes and spectrographs to learn

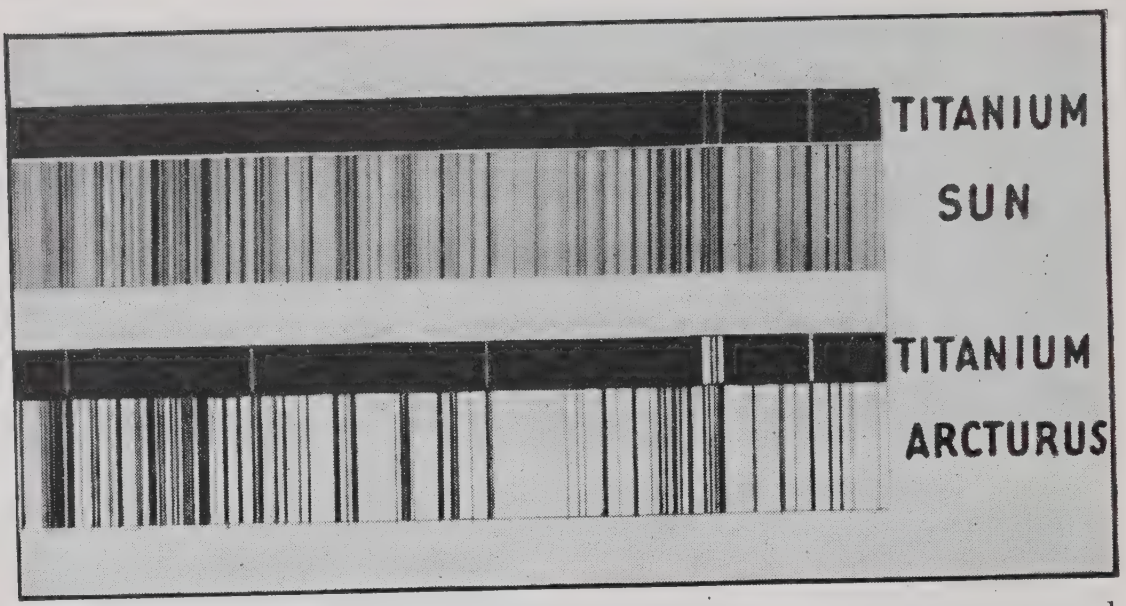


FIG. 51. Part of the spectrum of the sun and of Arcturus are compared with lines from the light of the element titanium in the laboratory. Notice how each bright line from the element is matched by a dark line in the spectrum. This tells scientists that gaseous titanium is found in the atmosphere of both the sun and Arcturus. The other dark lines are from other elements.

what kinds of materials the sun and stars are made of. How can they do this?

To learn how a spectroscope can analyze starlight, you need to know a few new facts about the way elements behave on the earth. When some substance containing the element sodium is vaporized in a flame, it gives a very bright yellow light. When this light is sent through a good spectroscope, two yellow lines can be seen very close together in a certain place in the instrument. No other element gives two lines in exactly this position. Therefore, when a scientist finds these yellow lines in the spectrum of any substance, he knows that the substance contains sodium.

Each element has its own peculiar set of lines; and usually there are many lines, rather than a few. Iron, for instance, produces hundreds of lines. By vaporizing any

unknown substance and causing it to give out light, either in a flame or by means of electricity, scientists can tell just which elements are present in a substance.

The material in the sun and in most stars is glowing gas. Thus each element in these heavenly bodies gives out its own particular colors of light. When they reach us, they are mixed up. By using the spectroscope, astronomers can separate the different colors and find the lines that come from the different elements in the sun and stars. The light from nearly sixty elements has been found in sunlight. Among these are such common elements as calcium, hydrogen, iron, magnesium, nitrogen, oxygen, silicon, and sodium. Lines from an unknown element, that was named helium ("sun element"), were found in the sunlight more than twenty-five years before the element was discovered on the earth.

Self-Testing Exercises

1. What was the first instrument used by astronomers?
2. Why are telescopes the most important instruments used by modern astronomers?
3. Name two kinds of telescopes. Explain briefly how each kind works, using diagrams.
4. How do astronomers measure the distance to a body in the solar system? To one of the nearer stars?
5. What does a spectroscope tell scientists about stars? How does it work?

Problems to Solve

1. List as many reasons as you can why a large reflecting telescope is more practical than a large refracting telescope.
2. Give some of the ways in which mathematics is useful to an astronomer.
3. Use a reading glass, a magnifier, and a tube of some kind to make a telescope that you can use to look at the moon.

LOOKING BACK AT UNIT 1

1. This unit emphasizes a number of important scientific ideas. You should have most of them clearly in mind. Without your book try to write all the "big ideas" of the unit in a list. The sub-problems of each problem will help you see what these big ideas are. State each one in a complete sentence, thus:

a) The earth is a ball 8000 miles in diameter, composed of a solid part, a water part, and the air.

b) We believe that the earth is a sphere because we cannot explain a number of facts unless it has that shape.

c) Our solar system is .....

2. In your list for Exercise 1 put a star in front of the ideas that seem most interesting and important to you.

3. After your study of Unit 1 you should understand the following words. Show in some way that you understand them. You can show your understanding in any one of several ways: (*a*) by giving a definition of each one in your own words, (*b*) by using the word in a sentence, (*c*) by giving an example, (*d*) by telling something about each one.

star	*galaxy*	*latitude*	*hypothesis*
comet	*nebula*	*longitude*	*constellation*
orbit	*eclipse*	*meteorite*	*solar system*
planet	*universe*	*astrologer*	*sun time*
meteor	*sun-spot*	*astronomer*	*standard time*

ADDITIONAL EXERCISES

1. The longest and shortest days occur about June 21 and December 21. However, the warmest and coldest weather do not usually come until about a month after these dates. Explain why.

2. Make a booklet telling of people's early beliefs about astronomy.

3. Make a booklet of important astronomers, telling about their lives and their work. Include such men as Galileo, Kepler, and Copernicus.

4. Make a North-Star finder like the one shown in Figure 52. On some clear, dark night, go into the open where there are no trees or buildings to obscure your view. Push the sharpened end of a broomstick firmly into the ground and turn the pointer north by means of the compass.

By means of the protractor set the pointer to correspond with the number of degrees of latitude where you live. Sight down the pointer and you should be able to find the North Star.

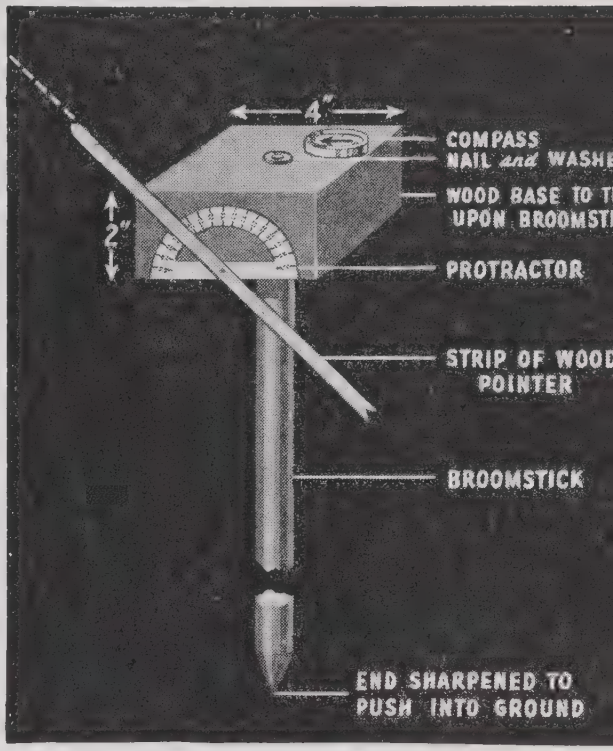


FIG. 52. Apparatus for Additional Exercise 4

5. Here is an easy way to get an idea of how far the planets are spaced from the sun. Tie one end of a large ball of wrapping twine to a post on the playground. Let the post represent the sun.

Using a space-scale of one inch to 36,000,000 miles, refer to the table on page 20 and figure out the distances each planet would be from the sun according to your scale. For example, if one inch equals 36,000,000 miles on your scale, Mercury would be one inch from the post, which represents the sun. Make a loop in the cord at this place and tie a paper clip here. Place a card in the paper clip marked "Mercury."

Do the same for each of the other planets. You may be very much surprised at the results of the exercise.

6. Make a sun dial and use it for telling sun time, or solar time. Fasten a square or round board firmly to the top of a strong post. Be sure it is level. Fasten a large spike nail or heavy wire vertically in the board near its center.

By using a compass or "sighting" at the North Star at night, draw a line on the board straight north of the wire. On a sunny day set your watch at twelve o'clock noon when

the shadow of the wire points straight north. Then make marks where the shadow falls at the other hours of the day.

7. Look at Figure 20, page 27. The principal craters, mountains, and plains of the moon are shown. When the moon is full, get a pair of field glasses and locate these features on the moon itself.

8. Read in reference books about the great telescopes of the world.

9. Why is the Arctic circle just $23\frac{1}{2}$ degrees away from the North Pole?

10. Why is the Tropic of Cancer $23\frac{1}{2}$ degrees from the equator?

11. If you wish to do some further work in astronomy, obtain an astrolabe (a kind of star-finder) made by the Geographic Press of Columbia University, New York City. This device will enable you to locate stars easily and to learn many other things about the movements of heavenly bodies.

FIG. 53. As you may remember, Aristotle, the famous Greek thinker of long ago, believed that small or light objects fell more slowly than large or heavy objects. But Galileo doubted this; so he decided to find the truth by an experiment. From the top of the famous Leaning Tower, in Pisa, Italy, he dropped a heavy ball and a light ball at the same instant. Which ball reached the ground first? What is this mysterious force, *gravity*, that makes things fall toward the earth?

UNIT TWO

UNIT 2
HOW IS THE FORCE OF GRAVITY USEFUL TO US?

INTRODUCTORY EXERCISES

*1. What do we mean when we say that all matter is made of molecules?

*2. Describe an experiment to show that gravity pulls on the air; that is, that air has weight.

3. Why does a feather fall more slowly than a coin?

4. Explain why water squirts out sidewise when a hole is bored in the side of a barrel full of water.

5. Why do stratosphere balloonists seal themselves inside a metal ball when they start their trips that carry them miles above the earth?

6. Why was it necessary for the steel walls and quartz windows of Beebe's bathysphere to be very thick when it was lowered a half mile into the ocean?

7. Does a falling brick have gravity, or does the earth have gravity, or do they both have it? Explain why you answer as you do.

8. Give as many uses of gravity as you can.

9. A ten-pound stone and a 100-pound stone were dropped at the same instant from the top of a tower 150 feet high. Did one stone strike the ground before the other, or did both strike at the same time?

10. Where have you ever seen a barometer? What was it used for?

11. Does gravity help supply your home with water? If so, how?

12. When you drink milk or "pop" through a straw, does the liquid go up into your mouth because of a pull from your mouth or because of a push on the liquid? Explain.

FIG. 54. Every time you dive into the water, gravity pulls you down. Then, as you will learn in this unit, gravity strangely enough causes the force that pushes you up to the surface of the water again.

LOOKING AHEAD TO UNIT 2

OF COURSE you remember when you fell off your bicycle, lost your balance while roller-skating, or tumbled down stairs. Gravity gave you a jolt to make you remember. Perhaps you have let a heavy box slip and had gravity bruise your toe! You may have slipped on the ice and had gravity jerk you down so hard that you wanted to cry!

You have had so many things like these happen to you that you take the force of gravity for granted; you expect anything to fall downward if you let it slip from your hands. If you see something going upward that really ought to go down, you wonder why it is going up. The balloon man at the circus makes money because he sells things that overcome gravity and go up instead of down.

Have you ever wondered just what gravity is? What queer kind of "rubber band" must be attached to everything to pull it back to earth after it has been lifted up? Did you ever stop to think that all the different kinds of

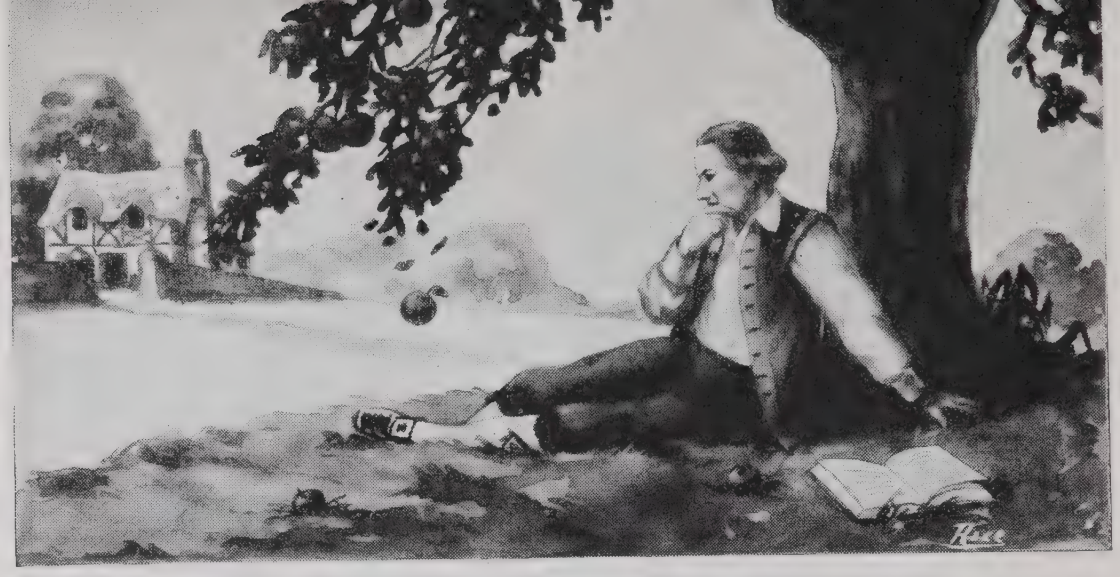


FIG. 55. Isaac Newton was a professor at the great University of Cambridge about 275 years ago. One year the university was closed, and Newton went home to the country. There, according to a story that his niece told, he was resting in an orchard one day when an apple fell off a tree and rolled along the ground. The falling apple set him wondering why objects fall down instead of up.

legs and wings animals have, the foundations we use in our buildings, and many of the wheels in our machines were made to resist the force of gravity?

About 275 years ago a falling apple set Sir Isaac Newton wondering about gravity. What makes an apple fall down instead of up? How far out into space does gravity go? Can it reach as far as the moon? If it does, why doesn't the moon fall on the earth? Does gravity pull on everything? And, if so, does it pull on all things with equal force?

Newton did not stop thinking about gravity at the end of five minutes or of five days. He continued his study of gravity for a long time and worked out many hard mathematical problems that helped him find answers to the questions he had been wondering about. Twenty years later he proved that the moon is held in its orbit by gravity, and he wrote down a very important scientific law called the *Law of Universal Gravitation.*

Now, we are not going to ask you to think about gravity for twenty years, but we are going to ask you to think

about it for a few days. You will find that it is well worth thinking about, for it helps you as much as it hinders you. Do not just read what your book tells you and then stop thinking. While you are studying this unit, think about gravity at home, on the street, during ball games, everywhere! Discover for yourself why you sometimes have to work against gravity and how you use it. Then the knowledge that you have about gravity will be your very own.

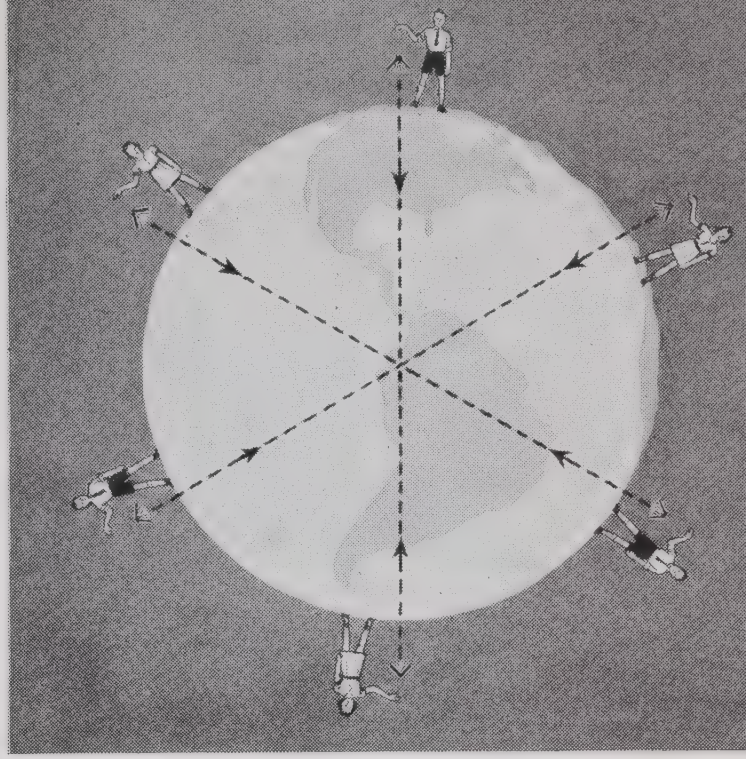


FIG. 56. If you imagine that objects keep on falling into the earth, you find that they meet at the center of the earth.

Problem 1:

WHAT EFFECTS DOES GRAVITY HAVE?

HOW DO FALLING BODIES ACT? For a long time scientists have been trying to find out what gravity is, but they cannot yet explain to us what it is. Therefore, when we study gravity, we can only study what it does.

Pick up the nearest book. Hold it out and let go of it. You know what will happen without doing the experiment. You say that any object that is not held in some way will fall down to the ground. But which way is "down"? It is always toward the earth. If you drop an object at any place on the earth's surface, it will always go down, that is, toward the earth.

Figure 56 shows what happens when objects are dropped at different places around the earth. It is just as if the force of gravity were concentrated at the center of the earth. Of course, if the wind or something else

gives a falling object a push to one side, it does not fall straight down. But the pull of gravity is, in most places, toward the center of the earth.

Would you rather have a baseball dropped on your head from a first-floor window or from a second-floor window? Of course, if the ball must hit you, you will choose to have gravity pull on it only from the lower window to your head. The reason is that gravity keeps pulling on things even while they are falling. Thus, the longer most things fall, the faster they go. The faster they are going when they hit you, the harder they strike.

FIG. 57

But some things do not seem to move faster and faster as they fall. For example, leaves, sheets of paper, and feathers do not gain speed as they fall. The way these things fall makes many people think that small things always fall more slowly than large ones. But Galileo long ago proved that weight makes no difference in how fast objects fall. When he dropped a small weight and a large one from the top of a tower at the same instant, they both reached the ground at the same time.

Since Galileo's time scientists have worked out another experiment to prove the truth of what Galileo discovered. A feather and a piece of lead are put in a long tube (Figure 57). All the air is then pumped out of the tube. When the tube is quickly turned upside down, the feather falls just as fast as the lead. This experiment and many others like it show that the weight of an object really does not make any difference in how fast gravity makes it fall. The reason that leaves and sheets of paper do not gain speed is that the air holds them back. The larger the surface of a falling body, the greater the

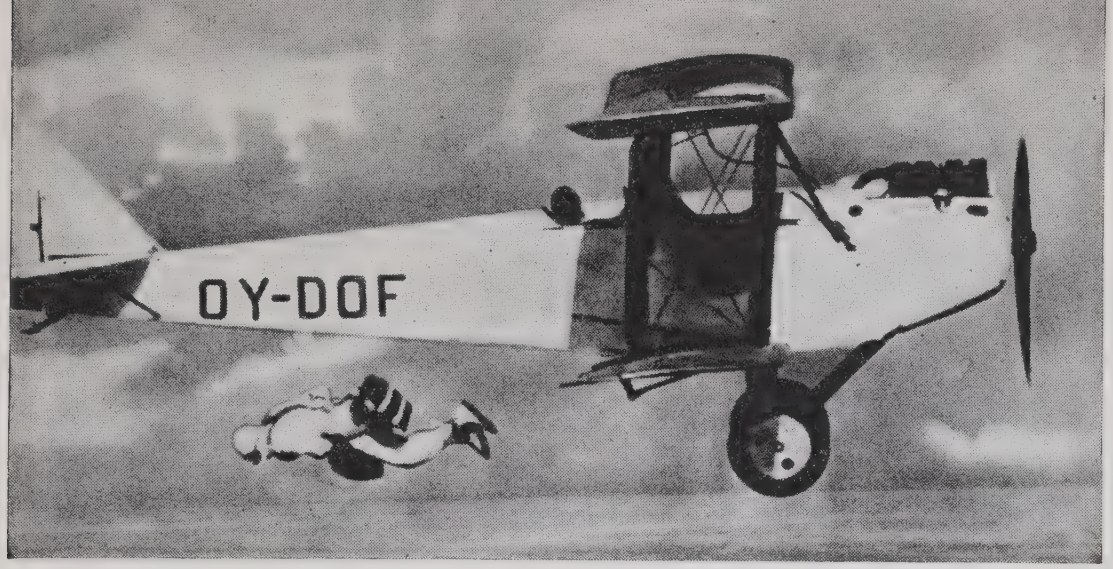


FIG. 58. Parachute jumpers use the resistance of the air to help them land safely. They allow themselves to fall for a few seconds; then they pull a cord that releases the parachute. The surface of the open parachute is so great that the resistance of the air slows down the speed; therefore, the jumper is not hurt when he reaches the ground.

resistance of the air to the body. Objects with large surfaces fall more slowly than objects with small surfaces.

Another interesting experiment that tells us about falling bodies is performed by dropping a man-sized dummy from an airplane. Motion pictures of the falling dummy show that the dummy falls faster and faster until it is going at the rate of 120 to 140 miles per hour. From this point on, it falls no faster. The reason for this is that as the dummy falls faster and faster, the air pushes against it harder and harder. You have noticed this when you have ridden at high speed in an automobile. Finally, the resistance of the air is great enough to overcome the pull of gravity; then the dummy can fall no faster.

Here is another interesting problem about the pull of gravity. What happens to objects that are thrown out parallel to the earth's surface? Does gravity pull a speeding rifle bullet down to the earth as quickly as it does a bullet that is merely dropped from the end of the gun barrel? You can find the answer by doing a rather simple experiment.

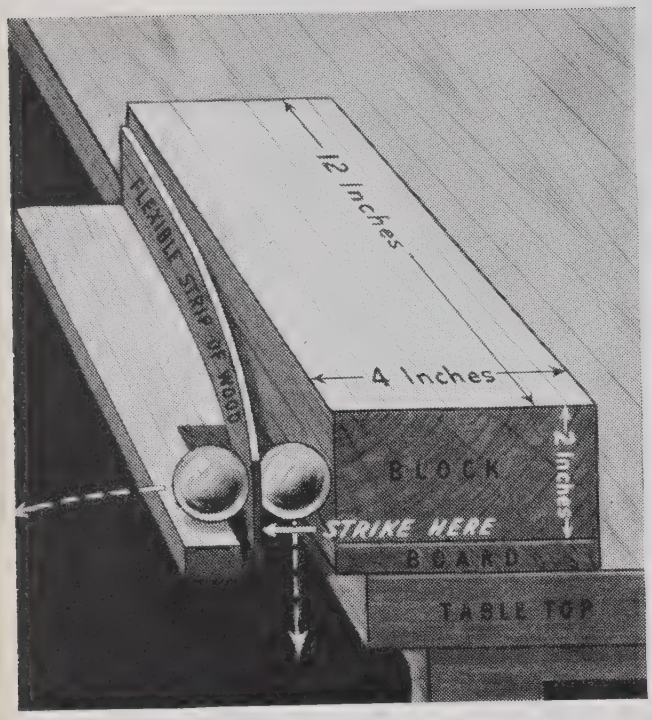


FIG. 59. Experiment 7

EXPERIMENT 7. *How Does Gravity Act on Objects That Are Moving Horizontally?* Construct an apparatus like the one shown in Figure 59, and fasten or hold it firmly on the end of a table. Place two marbles in the apparatus so that they are exactly the same distance from the floor.

Have someone strike the end of the flexible strip a light blow with a hammer, so that one marble is shot out horizontally and the other starts to fall straight down at the same instant. Watch and listen carefully so that you will know whether the two marbles strike the floor at the same time.

Very careful study has shown that the speed at which an object is moving horizontally makes no difference in the pull of gravity. Two forces are acting on the rifle bullet. The explosion of powder in the shell drives the bullet forward. The force of the gravity of the earth pulls it downward. The attraction of the earth will cause it to gain speed toward the center of the earth at just the same rate as if it had been dropped. Thus, a rifle bullet shot out parallel to the earth's surface strikes the ground at the same time as it would if dropped straight down from the end of the rifle barrel.

Artillery officers use this knowledge of the force of gravity in calculating where the shells of their great guns will fall. In addition, they must know how high into the air the muzzles of the guns are pointed, how fast the shells are going when they leave the guns, and how much they are slowed down by air resistance.

Self-Testing Exercises

1. Do objects all over the earth fall in the same direction? Explain.

2. Does a falling stone gain speed as it falls? Explain.

3. If an object is dropped from a great height, will it continue to fall faster and faster as long as it is falling? Explain your answer.

4. Why is a man without a parachute killed when he jumps from an airplane, while a man who falls with an open parachute is not injured?

5. How did Galileo prove that Aristotle was wrong in believing that a small stone or other object falls more slowly than a large one?

6. Does gravity pull as hard on a moving bullet as it does on one that is standing still?

Problems to Solve

1. Drop a feather and the lid of a can at the same time. Do they both reach the ground at the same time? Now put the feather on the lid and drop the lid. What happens? Explain the difference in results.

2. Is the speed of a bullet that is fired straight up in the air as great when it strikes the ground as when it leaves the gun? Explain.

3. In building a brick wall, the brick layers hang a string with a weight on it down the side of the wall. This is called a *plumb line*, and it is used to help the brick layers keep the bricks in a straight vertical line as they place them one on another (Figure 60). Explain how it works.

4. How do you think that air resistance changes the distance that a gun can shoot a bullet?

FIG. 60

WHAT BODIES HAVE GRAVITY? When Sir Isaac Newton began his study of gravity and the moon, no one knew what made the moon travel in an almost circular path around the earth or what made the earth stay in its path around the sun. Scientists have discovered that any moving body travels in a straight line unless some force pushes or pulls it aside. Therefore the moon would be expected to shoot on by the earth and off into space. Something must make it travel in a curve. Newton was able to prove that it is the earth's gravity that keeps the moon from going off into space (Figure 61).

As a result of Newton's studies and of many experiments, we now know that all matter has this mysterious ability to pull other matter toward itself. Every tiny bit of stone and water on the earth pulls on all the other bits. The earth as a whole pulls on all materials that are on the earth and above the earth. In the same way the moon, the planets, and the sun pull on each other.

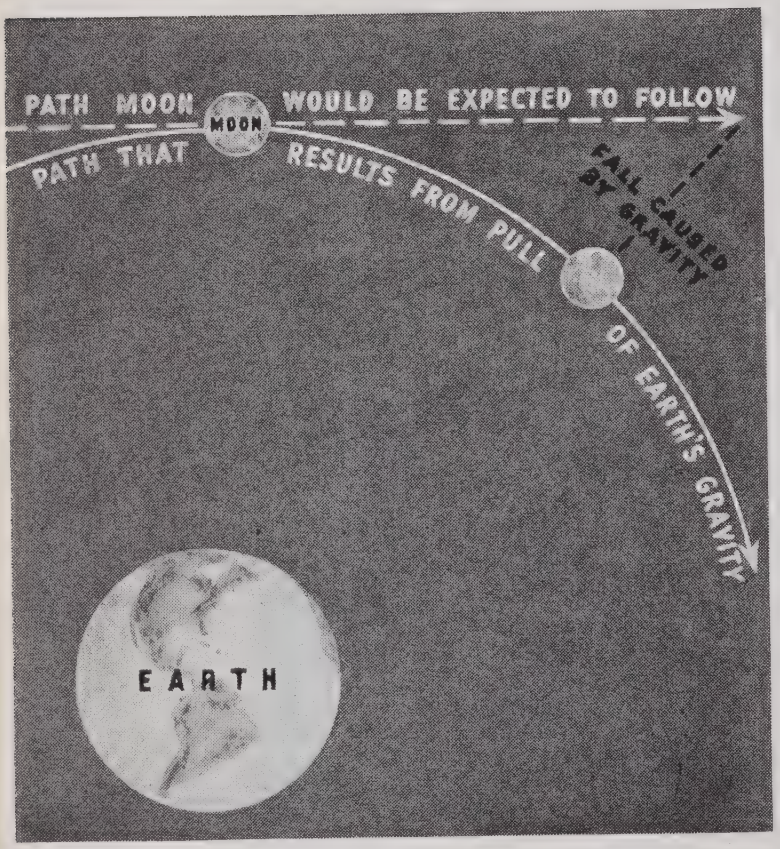


FIG. 61

Scientists call this characteristic that all matter has *gravitation* or *gravitational attraction*. Every body of material in the universe has gravitational attraction for every other body. The word *gravity* is used for the pull of the earth on other bodies of matter. That is, gravity is the gravitational force of the earth.

Scientists have carried out a number of experiments to show that all things attract each other. In one experiment that you can easily understand, scientists hung two "plumb lines" on opposite sides of a mountain (Figure 62). Then they carefully studied the directions in which the lines pointed. They found that the lines did not point straight toward the center of the earth. The weights on the lines were pulled over by the material in the mountain, as shown in the drawing. The difference in the direction of the lines was so small that delicate instruments were needed to measure it.

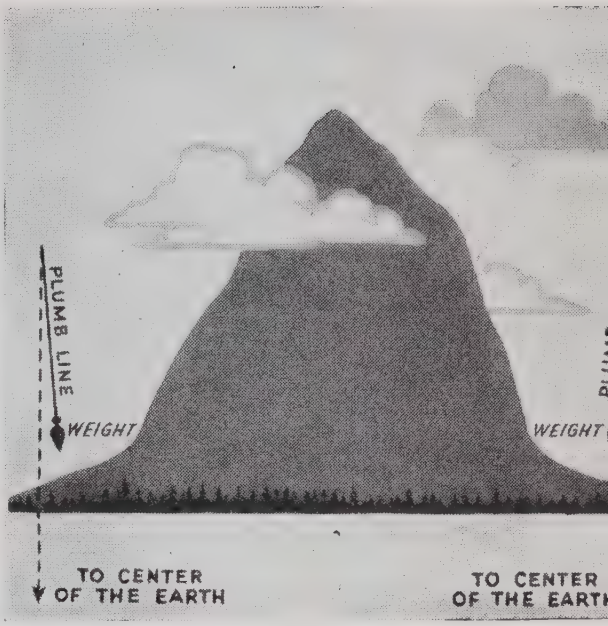


FIG. 62. In this drawing the plumb lines are shown much longer than they really were, so that you can understand how the experiment was done.

Because he learned that all matter possesses gravitation, Newton began his statement of the Law of Universal Gravitation in this way: *Any two objects in the universe attract each other.* From this statement and from what you have learned in the preceding paragraphs, you can see that it is not correct to think only that a brick is being pulled by the earth. The brick also pulls on the earth. When we "lift" the brick, what we do is to pull the earth and the brick apart.

Let us now see what you have found out that is most worth remembering. Think of the last big idea first.

First, you have learned that all matter attracts all other matter. This is another way of saying that all matter has weight, as you learned in Book One. This characteristic of matter is called gravitation; that is,

scientists say that all matter has gravitation. The earth's gravitational pull on other things is called gravity.

Second, gravity tends to pull things from all directions toward the center of the earth.

Third, gravity tends to make all objects near the earth fall at the same rate. As objects fall, they go faster and faster unless air resistance interferes. This air resistance is greater on things that are falling very fast and on things that have a large surface.

Self-Testing Exercises

1. (*a*) Draw a diagram that shows how the moon moves around the earth and how gravity keeps the moon in its path. (*b*) Write an explanation of your diagram.

2. What is the difference between the meanings of the words "gravitation" and "gravity"?

3. Describe an experiment which shows that the rock of a mountain has gravity.

4. State the first part of the Law of Universal Gravitation.

5. Give two ways in which scientists think that gravity may have helped form the solar system. (See page 34 if you do not remember.)

Problems to Solve

1. Give one or more reasons why you do not feel the gravitational pull of a large building as you walk past it.

2. How would conditions be different if gravity should stop acting? Make a list of the changes you can imagine.

3. Does the moon pull on the earth? Give reasons for your answer.

4. Draw a diagram to show how the gravity of the sun holds the planets in their places.

5. Draw a diagram to show how Jupiter would change the path of the earth when the earth is between Jupiter and the sun.

FIG. 63. The picture was found on a vase made thousands of years ago. It shows an Egyptian king watching the weighing of bags of grain. A wooden beam suspended from the middle was probably the first kind of scales or balances ever used.

Problem 2:

HOW DO WE USE GRAVITY TO MEASURE MATERIALS?

WHAT IS "WEIGHT"? For several years you have been very much interested in the pull of gravity. Every time you have stepped on a scales to weigh yourself, you have wanted to know how hard gravity was pulling on your body. As you grew, your body was adding more matter to itself. You found that each year gravity was pulling harder on you because there was more of you. You described this extra pull by saying that you weighed a certain number of pounds more than you did the year before.

But why do we use scales to weigh things, and what do we mean when we say that something weighs so many pounds or kilograms? When men first began to measure amounts of materials, they used a number of different ways. One of the most common ways was to use a stone of convenient size. If they wanted some wheat, they would pour wheat into a basket until the wheat weighed as much as the stone. In other words, they compared the pull of gravity on the wheat with the pull of gravity on

the stone. When the pull was the same, they said that they had a "stone" of wheat. In England today it is still common to hear people say that a person or an animal weighs so many "stone." A "stone" has come to mean fourteen pounds.

What you do in weighing, then, is to compare the pull of gravity on the piece of matter you want to know about with its pull on weights that have a known amount of matter. This comparison is made in different ways. Scientists use balances with equal arms on the two sides of a pivot, or *fulcrum*, as shown in Figure 64. The object or material to be weighed is placed on one side and known weights are added to the other side until the two sides balance. Then the scientist knows that the amount of matter in the object is the same as that of the weights he placed on the other side, because the pull of gravity on the two sides is the same. Sometimes grocery stores use scales that work the same way. If you buy a pound of meat, the butcher places a pound weight on one side of the balance and adds meat to the other side until the two sides balance.

Springs can be used for weighing because, if they are not loaded too heavily, they stretch twice as far for two pounds of pull as for one, three times as far for three pounds, and so on. However, springs can be overstretched so that they do not weigh accurately. They also expand and contract with changes in temperature. These changes make them inaccurate; therefore, in most places it is against the law to use spring scales or spring balances in buying and selling.

WHAT ARE TWO SYSTEMS OF WEIGHING MATTER? When you weigh yourself, your dog, a bag of sugar, or a pail of milk, you want to know how much matter there

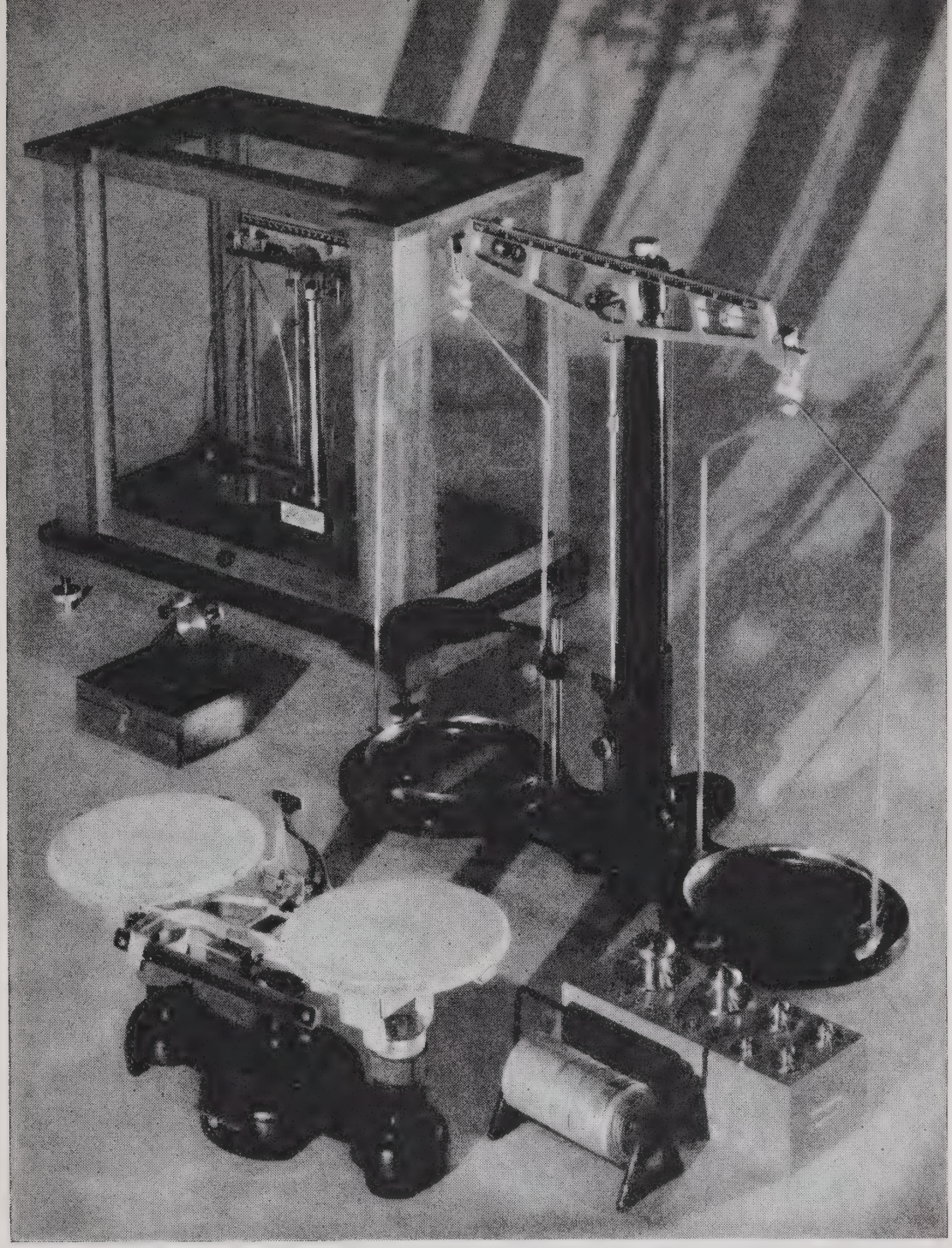


FIG. 64. These finely made scales use the same principle that the Egyptians used long ago to measure the pull of gravity on materials. Notice the weights for the two balances at the lower right side of the picture. (Central Scientific Co.)

is in the object you are weighing. To do this by using gravity, you must have some standard amount of matter to compare with. When people first began to weigh things, they used many different standards, like the stone you read about on page 81. But at last they came to see

FIG. 65. These are the two standard kilograms kept at the Bureau of Standards, in Washington, D. C. They are 90 per cent platinum and 10 per cent iridium. These metals will not rust.

that they must have standards that meant the same to everyone.

The standard unit of matter is a piece of metal kept in the International Bureau of Weights and Measures at Sèvres, France. It is a solid cylinder made of platinum and iridium. Two very accurate copies of it are kept at the Bureau of Standards in Washington, D. C. All the important nations of the world have agreed that this weight shall be the standard for measuring the amount of matter in things. This standard of weight is called one *kilogram*. A pound is .45359 of a kilogram; that is, a pound is little less than one-half a kilogram. Now let us see how the kilogram is used.

Two systems of weights are commonly used in scientific work and in buying and selling materials. One system is based on the kilogram; the other is based on the pound. The system based on the kilogram is called the *metric system*. This is used by scientists everywhere and for trade in most countries except the British Empire and the United States. The system based on the pound is

called the *English system*, and is commonly used in English-speaking countries. Some common units of the metric system of weights and their equivalents in the English system are shown in Table 2.

The metric system is a decimal system, like our money system; that is, the different weights are ten, one hundred, or one thousand times each other. In the table below, each weight given is 1000 times the preceding weight. Other units, less frequently used, are ten and one hundred times the milligram and gram. Changing kilograms to metric tons or to grams is just as easy as changing dollars to cents. All you need to do is to move the decimal point the correct number of places. For example, 1260 grams is 1.26 kilograms. In the English system you must divide the number of ounces by sixteen to find the number of pounds. To find the number of tons you must divide the number of pounds by 2000.

TABLE 2. METRIC UNITS OF MASS AND THEIR PRACTICAL ENGLISH EQUIVALENTS

1000 milligrams	=	1 gram (g.)	=	$^1/_{28}$ ounce
1000 grams	=	1 kilogram (kg.)	=	2.2 pounds
1000 kilograms	=	1 metric ton	=	2204.6 pounds

WHAT IS THE DENSITY OF A MATERIAL? Has anyone ever asked you this question, "Which is heavier, two pounds of feathers or a pound of lead?" This question confuses many people for a moment because we have two meanings for the word "heavy." You are correct when you say that two pounds of feathers are heavier than a pound of lead. You are also correct when you say that lead is heavier than feathers. To avoid confusion of this kind in thinking about the pull of gravity on materials, scientists use a word that is helpful to all of us. That word is *density*.

FIG. 66. You can easily carry a cubic foot of cork under your arm, and you can just about lift a cubic foot of ice. But you cannot budge a cubic foot of iron.

The density of any substance is the amount of matter of that substance in a certain space. For example, the density of cork is 15.6 pounds per cubic foot, that of water is 62.4 pounds per cubic foot, and that of lead is 705 pounds per cubic foot. Notice that in thinking about density, you have to think about space, too. Density tells you how much matter will go into a certain amount of space. A box with one cubic foot of space in it will hold over 700 pounds of lead, but only about fifteen pounds of cork. Lead is a much denser material than cork. Liquids also have different densities. A cubic foot of space holds 62.4 pounds of water, about 42 pounds of gasoline, and 849 pounds of mercury.

Now if you have really understood the explanation, your answer to the catch question will be, "Lead is denser than feathers, if that is what you mean." And you will not be fooled if someone says: "Which is heavier, a pound of cheese with holes in it or a pound of cheese without holes in it?"

Self-Testing Exercises

1. Explain how gravity is used to measure matter.
2. Give one reason why it is often against the law to use spring scales.

3. (*a*) What is the metric system of weights? (*b*) Who uses it? (*c*) Give one advantage it has over the English system.

4. What is the standard unit of matter for the world?

5. What does the word *density* mean? Give the density of water and of one other substance as examples.

Problems to Solve

1. How many kilograms do you weigh?

2. About how many grams are there in a pound of sugar?

3. Examine several different scales or balances used for weighing things. Try to see how each kind works. If at all possible, make diagrams of the working parts to show how they compare the pull of gravity on a known weight with that on an unknown amount of matter.

4. Find in a reference book a table of densities and get the densities of some common materials. Make a list, beginning with the material of greatest density.

5. Find the density of water in the metric system. Can you think of any advantage in having the density such a convenient number?

6. Plan a way to find the density of a block of wood or stone. If possible, try your plan.

FIG. 67. The pull of gravity on a gallon of liquid depends on what kind of liquid it is.

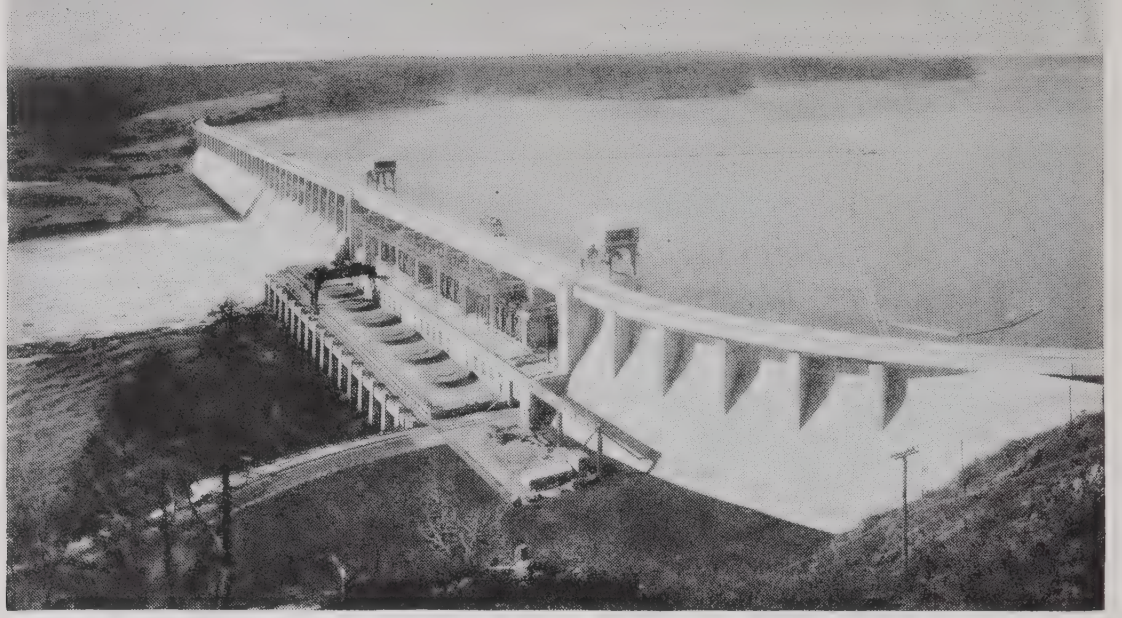


FIG. 68. As gravity pulls the water in streams down toward lakes and oceans, we place dams in the way of the water and use the force of the falling water to turn water-wheels. The water-wheels generate electricity for us.

Problem 3:

HOW DOES GRAVITY AFFECT LIQUIDS?

HOW DOES GRAVITY CAUSE PRESSURE IN LIQUIDS? You have learned many things about how gravity affects solid materials. You know that it pulls them all toward the center of the earth. You also know that gravity pulls on liquids just as it pulls on solids. Gravity makes rain (liquid water) fall to the ground and causes some of it to sink into the soil and enter wells. Some of it is pulled downhill in streams.

Everyone who has dived deep into a swimming-pool has felt the water pressing on his body. This pressure is caused by the pull of gravity on the water. You can show that there is pressure below the surface of liquids and can see how it works by a very simple experiment.

EXPERIMENT 8. *In What Direction Does Water Exert Force?* With a medium-sized nail and a hammer punch a hole from the inside out near the bottom of a tin can or bucket at least one foot deep. Put a wooden plug in the hole while you fill the can half full of water. Remove the plug from the hole and watch what the water does. In which direction does the water

move as it comes through the hole? In which direction must the water inside the can be pressing?

Close the hole again. Which way would the water move through a hole in the bottom of the can? Get a second can that will go inside the first one and punch a hole in the bottom of the smaller can. Press the smaller can down into the water in the large can. Which way does the water move through the hole in the small can? In what directions is the water in the large can pushing at that point?

FIG. 69. When a pail with holes is filled with water, water will pour out through each hole.

Your experiment shows, in the first place, that water inside a can pushes on the sides of the can. Of course you know that it also pushes against the bottom of the can. When you pushed the small can down into the water, you found that the water squirted straight upward through the hole in the bottom. This shows that the water at any point beneath the surface pushes up as well as down and sideways. Do you see, now, that the water beneath the surface of the water pushes in all directions?

From the same point water will run out through a hole in the bottom of a can, squirt out through a hole in the side, or run upward into another can. Careful measurements show that the water at any point pushes up and down and sideways with equal force. If it were not so, the water inside the can would move up or down or sideways in the direction of the least force.

This force inside the water is caused by the pull of gravity on the water. If there are ten pounds of water in

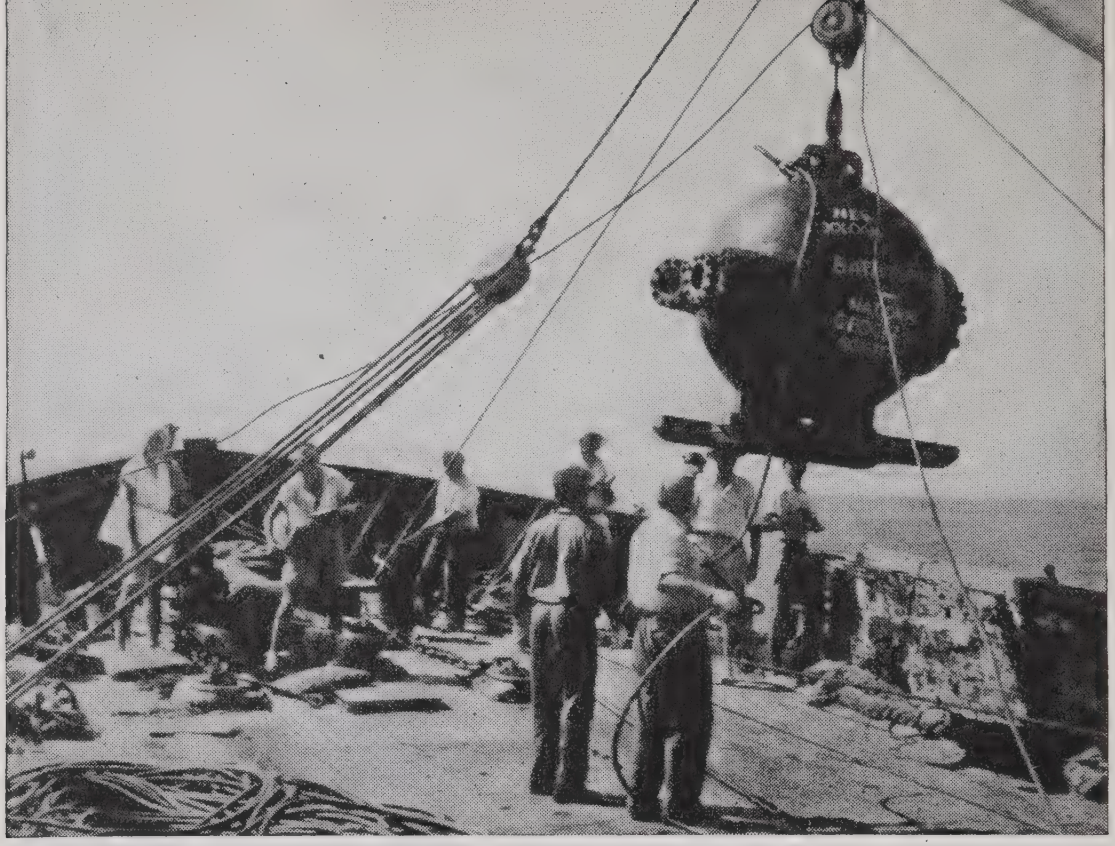


FIG. 70. Dr. William Beebe's steel sphere, called a *bathysphere*, is being lowered into the water with Dr. Beebe and his assistant inside. On the left side of the bathysphere are some of the windows.

a pail, the water is pushing down on the bottom of the pail with a force of ten pounds. Each tiny part of the bottom of the pail has to hold back its share of the force to keep the water in the pail. When a little piece of the bottom or side is removed, the water comes pouring out of the pail.

WHAT IS THE RELATION OF PRESSURE TO DEPTH IN LIQUIDS? A diver in an ordinary diving suit has gone down into the water about 400 feet. To go much deeper the diver must get into a strong metal armor that is very heavy and clumsy. Dr. William Beebe used a steel sphere with walls one and one-half inches thick and windows three inches thick. In this ball he was lowered 3000 feet below the surface of the water. Why is so much protection needed when men go down deep into water? You can begin to learn the reason by doing a simple experiment.

EXPERIMENT 9. *How Does the Pressure of Water Change with the Depth?* Punch two more holes outward in the side of the larger can used for Experiment 8. Use the same nail, and punch the holes directly above the hole you first made. Punch one hole about four inches from the top and the other halfway between the first two. Stop the holes with plugs and fill the can with water.

Raise the can some distance from the floor and remove all three plugs. Notice the force with which the water comes through each of the three holes. Try to write an answer to the problem of this experiment.

If you did the experiment carefully, you noticed that the water squirted out of the lowest hole with greatest force and out of the highest hole with the least force. To explain why water acts in this way, imagine that you have a deep rectangular can. The bottom is one foot square. Pour in water until it stands one foot deep. Since the can is one foot square, it contains one cubic foot of water. One cubic foot of water weighs 62.4 pounds. Therefore the bottom of the can must be holding up 62.4 pounds of water; that is, the pressure at the bottom is 62.4 pounds on one square foot. The pressure on the bottom of any can, pail, or tank is 62.4 pounds per square foot when the water is one foot deep. Therefore in any pool, pond, or lake the pressure of the water one foot below the surface is 62.4 pounds per square foot, or .43 pounds per square inch (62.4 divided by 144).

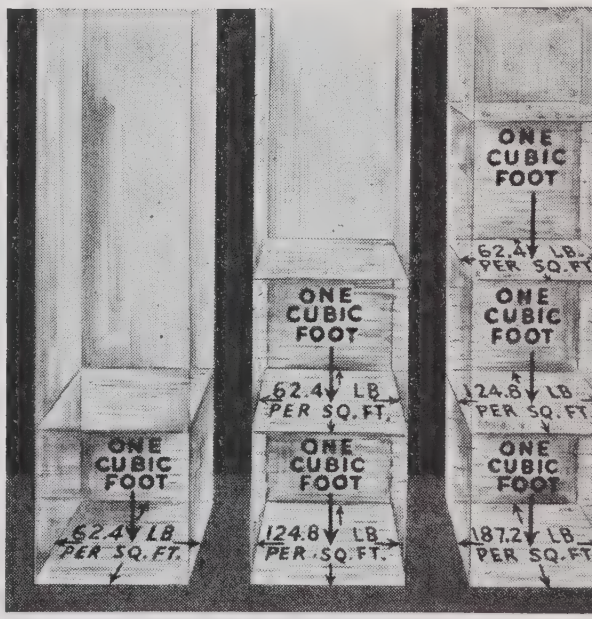

ONE CUBIC FOOT
62.4 LB PER SQ. FT.
ONE CUBIC FOOT
124.8 LB PER SQ. FT.
ONE CUBIC FOOT
187.2 LB PER SQ. FT.
ONE CUBIC FOOT
62.4 LB PER SQ. FT.
ONE CUBIC FOOT
124.8 LB PER SQ. FT.
ONE CUBIC FOOT
62.4 LB PER SQ. FT.

FIG. 71. The deeper water becomes, the greater its pressure is.

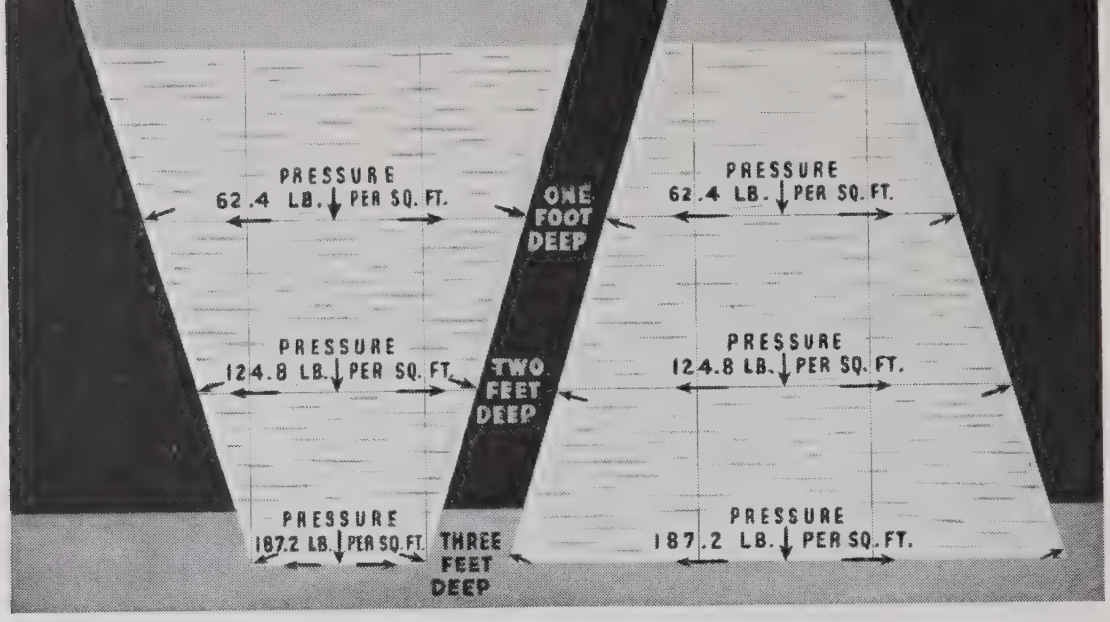


FIG. 72. The shape or size of a container does not change the pressure of water per square inch.

Now suppose that you pour another cubic foot of water into your can. The depth of the water is now two feet, and the pressure on the bottom is 124.8 pounds on one square foot. Pour in another cubic foot, and the pressure on the bottom becomes 187.2 pounds per square foot. One foot from the top of the water the pressure is 62.4 per square foot; two feet down it is 124.8 pounds. You see that the deeper the water, the greater its pressure.

Some people think that the shape of a tank makes a difference in the force per square inch at the bottom. That idea is shown to be wrong when we make careful measurements. The pressure of water at any point below the surface is always equal to the weight of the water above that point (Figure 72). For example, if water is 10 feet deep in a tank, the pressure is 624 pounds per square foot no matter what the shape or size of the tank. Of course, if the tank is filled ten feet deep with oil, the pressure at the bottom will be less because oil is less dense than water.

The old saying, "Water seeks its own level," is true because of the principle you have just learned. If a tank is connected to a pipe of any shape, the water in the pipe rises until it is level with the water in the tank

(Figure 73). Then the pressure from the water in the tank is equal to the pressure from the water in the pipe. If more water is put in either side, the depth becomes greater. The increased pressure on that side sends water into the other side until the two are equal again.

Self-Testing Exercises

1. Why is there pressure below the surface of any liquid?
2. Water squirts up through a hole in the bottom of a can when it is pushed into some water. What does this show about pressure in the water?
3. Explain why the pressure gets greater as a person goes deeper in water.

Problems to Solve

1. A dam similar to the one in Figure 75, page 95, holds back a lake thirty miles long. Another dam of the same height holds back a lake only one-half mile long. How does the pressure at the bottom of the first dam compare with that at the bottom of the second? Give the reasons for your answer.
2. There are places in the oceans where the water is more than six miles deep. No submarine has ever explored these "deeps." Why not?

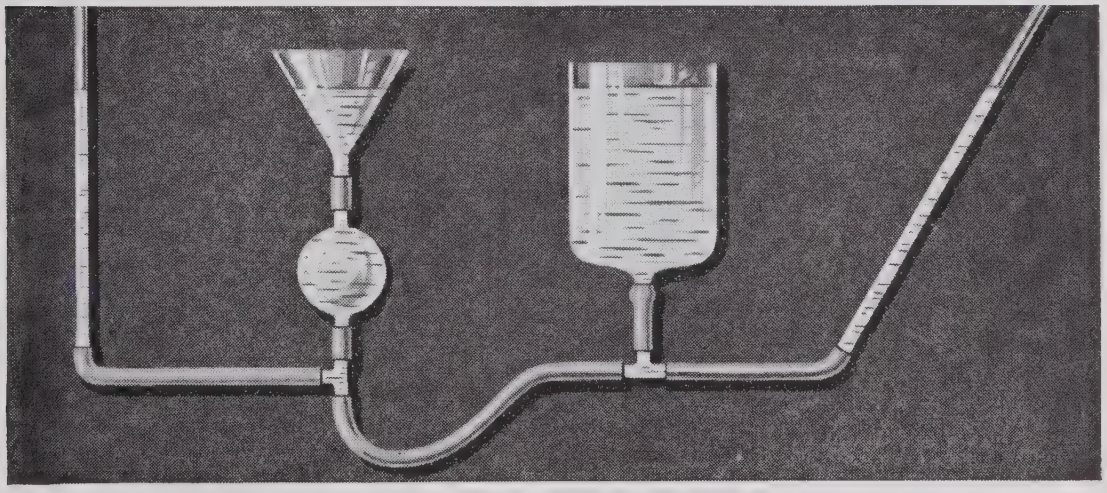


FIG. 73. The water in connected pipes stands at the same level.

3. Find the pressure in pounds per square inch on the bottom of tanks in which the water is (*a*) one foot deep, (*b*) three feet deep, (*c*) ninety feet deep.

4. The density of sea water averages about 64.75 pounds per cubic foot. Find the pressure in pounds per square inch on William Beebe's bathysphere (Figure 70) when it was lowered 3028 feet into the ocean in August, 1934.

5. One of the quartz windows of the bathysphere exposed about 28 square inches to the water. How many tons of force were pressing in on the window at the 3028-foot depth?

6. Figure 74 shows the geological structure that makes *artesian*, or flowing, wells possible. Explain why the water flows out of the mouth of the well without being pumped.

HOW IS GRAVITY USED IN WATER-SUPPLY SYSTEMS? Whenever we can, we like to have water brought to our homes under pressure. This pressure makes it run out through the faucets and hose nozzles. Gravity is used in many water-supply systems to produce the needed pressure.

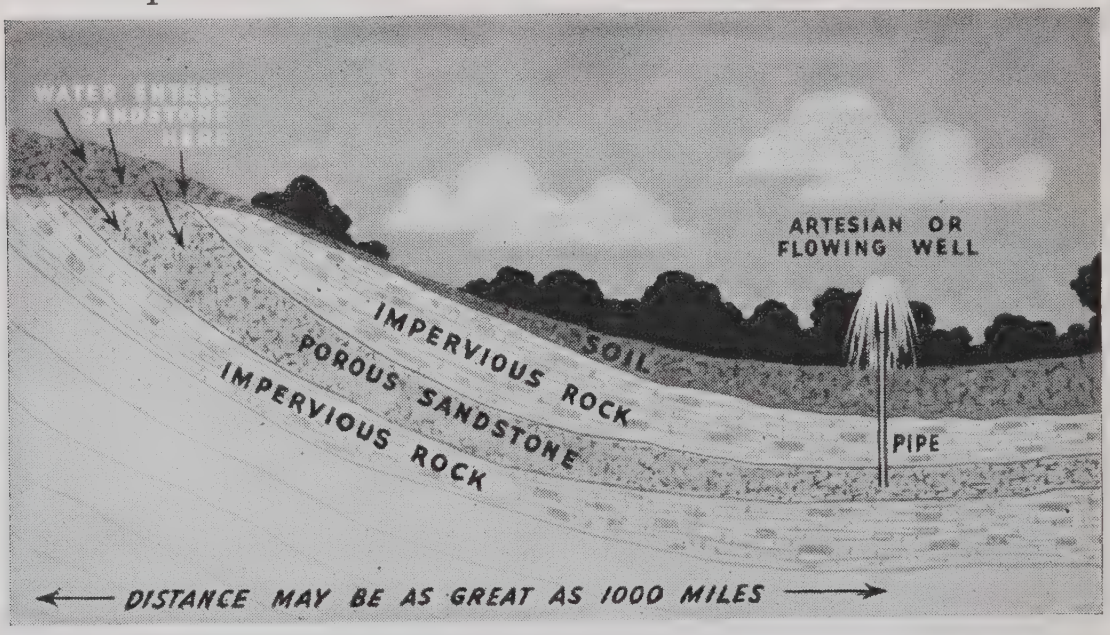


FIG. 74. Note that the source of the water from an artesian well may be a thousand miles from the well. *Impervious* rock is rock through which water cannot pass.

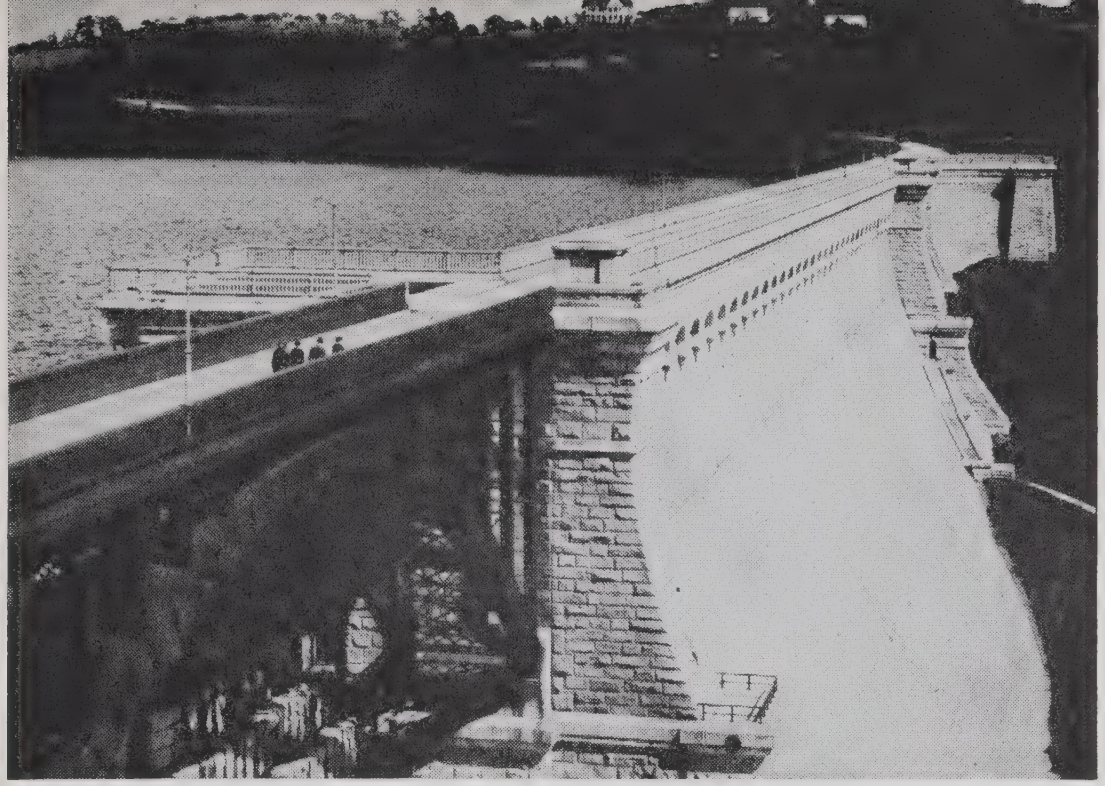


FIG. 75. Croton Dam, which makes one of New York's water-supply reservoirs, is 297 feet high and 1168 feet long at the top. Where is the dam thickest? Why is that part made thicker than the rest of the dam? (Ewing Galloway, N. Y.)

The simplest kind of gravity-pressure system has a water reservoir high up in hills or mountains. Often this reservoir is made by building a dam across the valley of a stream, as shown in Figure 75. Water from the artificial lake behind the dam runs into pipes leading down to the city. When little water is being used, each foot of water above a faucet causes a pressure of .43 pounds per square inch. If the water in a reservoir is 100 feet above a faucet, the pressure will be about 43 pounds per square inch. This is about the amount of pressure usually desired in city water systems.

If water is running through the pipes rapidly, the pressure is less. It is less because the water is held back a little by friction between the water and the pipes through which it is running. Thus the water cannot get to the faucet fast enough to keep the pressure as high as it is when the water is standing still.

New York and Los Angeles are two large cities that

FIG. 76. During part of its journey down from the high Sierras, the water supply for Los Angeles travels through huge pipes. Part of the way it travels through open ditches.

get most of their water from reservoirs high above the faucets. As New York has grown larger, more and more water has been needed. Therefore, the people were forced to go farther and farther from the city to find places for reservoirs. Some of the water used in the homes of the city is brought (by gravity) through pipe lines and tunnels that are 127 miles long. On its way it passes through hills and under rivers. Water from one reservoir is poured out into another reservoir lower down, until it is near the city. Then it enters the tunnels and pipes that run under the streets.

Since 1913 Los Angeles has secured water from Owens River, 250 miles away in the Sierra Nevada Mountains. The intake is 3000 feet above Los Angeles. If the water were brought directly to the city in closed pipes from that great height, the pressure would at times be as much as 1300 pounds per square inch. This pressure would be much too great for the water pipes to hold. The energy the water has because it is so high is used to run waterwheels and generate electric current at five power plants on the way down. At each power plant the water turns

water-wheels and then runs out into a reservoir much lower than the one before. From that reservoir the water flows down to the next power-house. The different reservoirs hold enough water to last Los Angeles for a year.

In many water-supply systems, pumps and gravity are used together to keep up the pressure. In farm homes a tank is often placed in a tower or in the attic. A pump operated by a windmill or a gasoline engine fills the tank. From the tank the water enters the water system. Gravity causes enough pressure to meet the needs of the users. As you already know, the tank must be above all the faucets where the water is to be used.

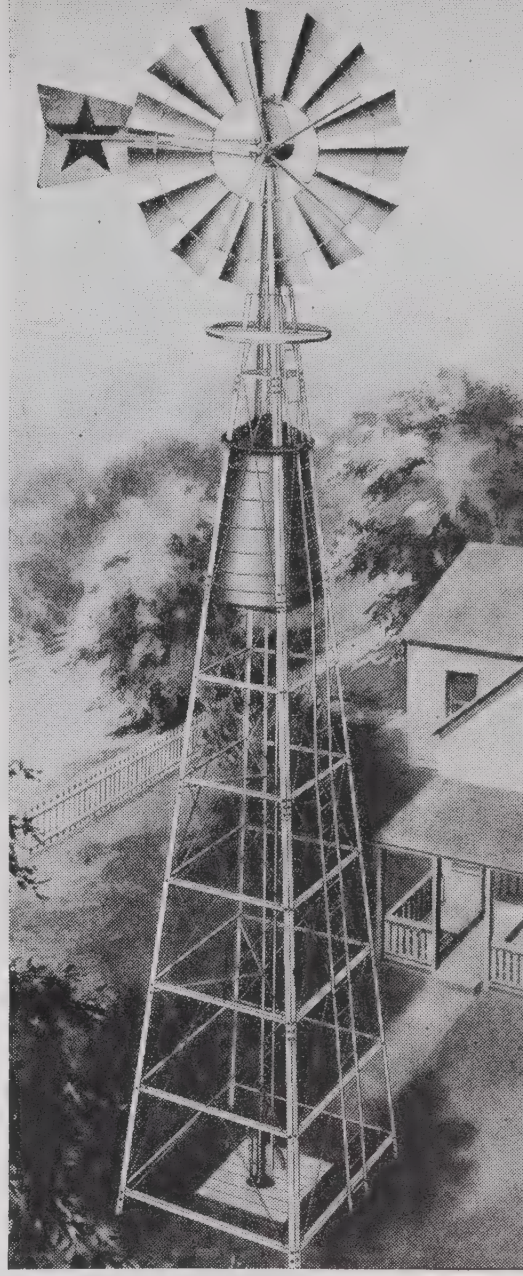


FIG. 77. This windmill pumps water up into the tank high above the house. Gravity pulls the water down into the pipes in the house.

In city water systems standpipes, or water towers, are often connected directly to the water pipes from the pumps. The pumps take the water from wells or streams and force it into the pipes. During the night when people are using little water, a fresh supply of water is forced up into the standpipe, or tower. Then, during the day, when the water is being used rapidly, gravity forces this water out and helps the pumps keep up the pressure. These towers can often be seen in small towns, where they stand high above the buildings.

Gravity has still another important effect in all water systems. Because of the pull of gravity on the water in the

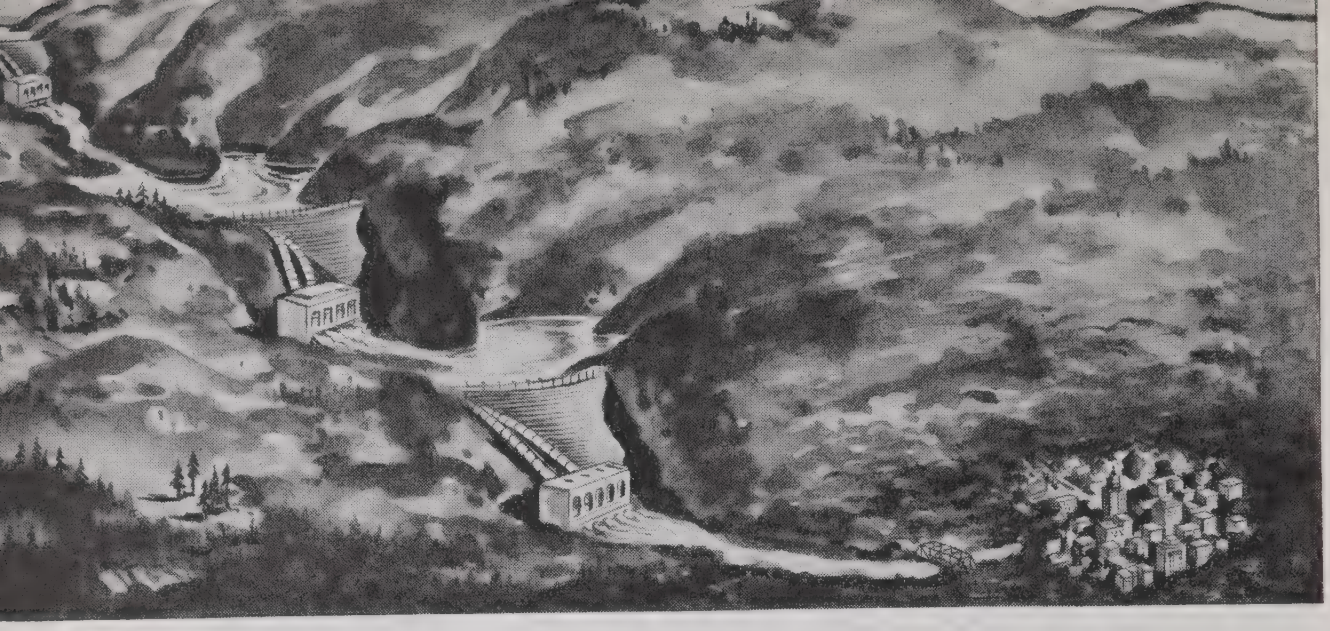


FIG. 78. Gravity may bring water right into our homes and at the same time run machinery that makes electricity to light our homes.

pipes, there is always a greater pressure at faucets on the first floor of a building than at faucets higher up. For the same reason, if all the faucets in a skyscraper are connected to one pipe, the pressure on the lower floors would be over 300 pounds per square inch when the pipe is full. This pressure is much too high for ordinary faucets and other fixtures. To avoid this trouble the builders of skyscrapers install a supply tank for each ten floors. Water runs from each tank by gravity to the ten floors below it. All the tanks are filled by pumps in the basement. In this way there is enough pressure on all floors but not too much anywhere.

Self-Testing Exercises

1. Draw a simple diagram to show how gravity can be used to send water (under pressure) into a home or city.

2. Tell how New York City or Los Angeles gets large amounts of water for city use.

3. Draw a diagram to show how pumps and gravity are sometimes used together to supply homes with water.

4. Why does water not run from a fourth-floor faucet as fast as it does from a faucet on the first floor of a building?

5. Why does a skyscraper need several separate water supply systems?

Problems to Solve

1. Why should the lower part of a standpipe (Figure 79) be stronger than the upper part?

2. Would a city-water system gain more pressure from a water tank of the shape shown in Figure 79 or from one of the type shown in Figure 80? (In both tanks the water-level would be 100 feet above the faucet where the pressure is measured.)

3. The pressure in a certain city water system is kept about 40 pounds per square inch at the surface of the ground. How high can a builder place faucets in a new building and still use the city water pressure to force water through them?

4. We must know two facts to calculate the pressure on a square foot of the bottom of a tank of oil. What are these two facts?

5. If your school is located in a town that has a water system, find how the pressure is kept up. Make a labeled diagram to show the arrangement.

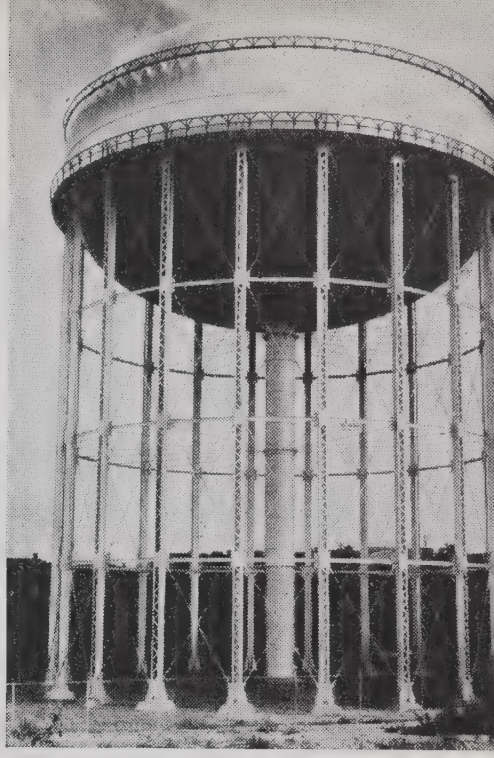


FIG. 79. This water tower at Spartanburg, South Carolina, is one of the largest in the United States. It holds 1,500,000 gallons of water. (Ewing Galloway, N. Y.)

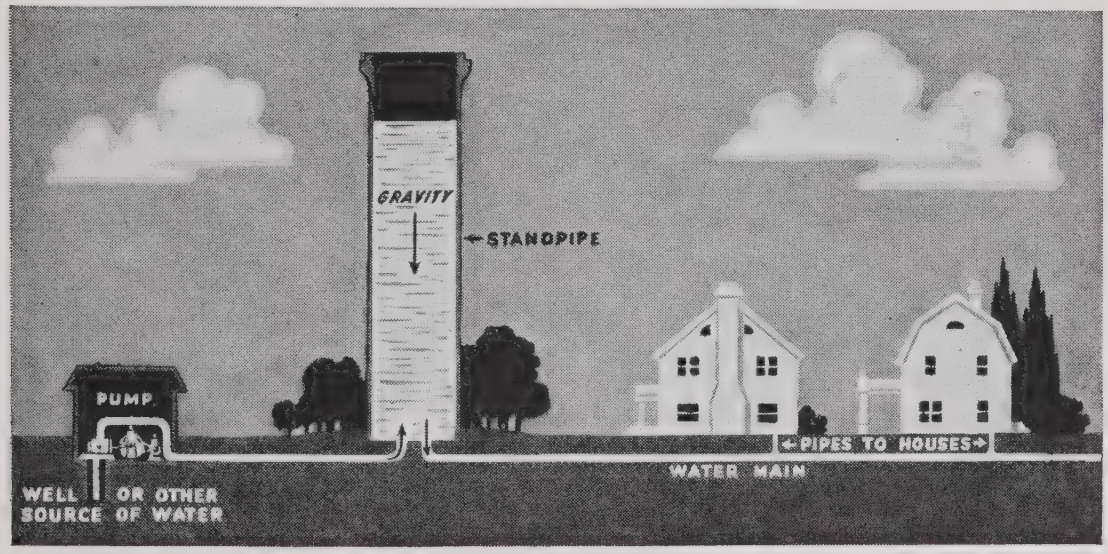


FIG. 80. How a pumping station and standpipe are used to supply water to buildings

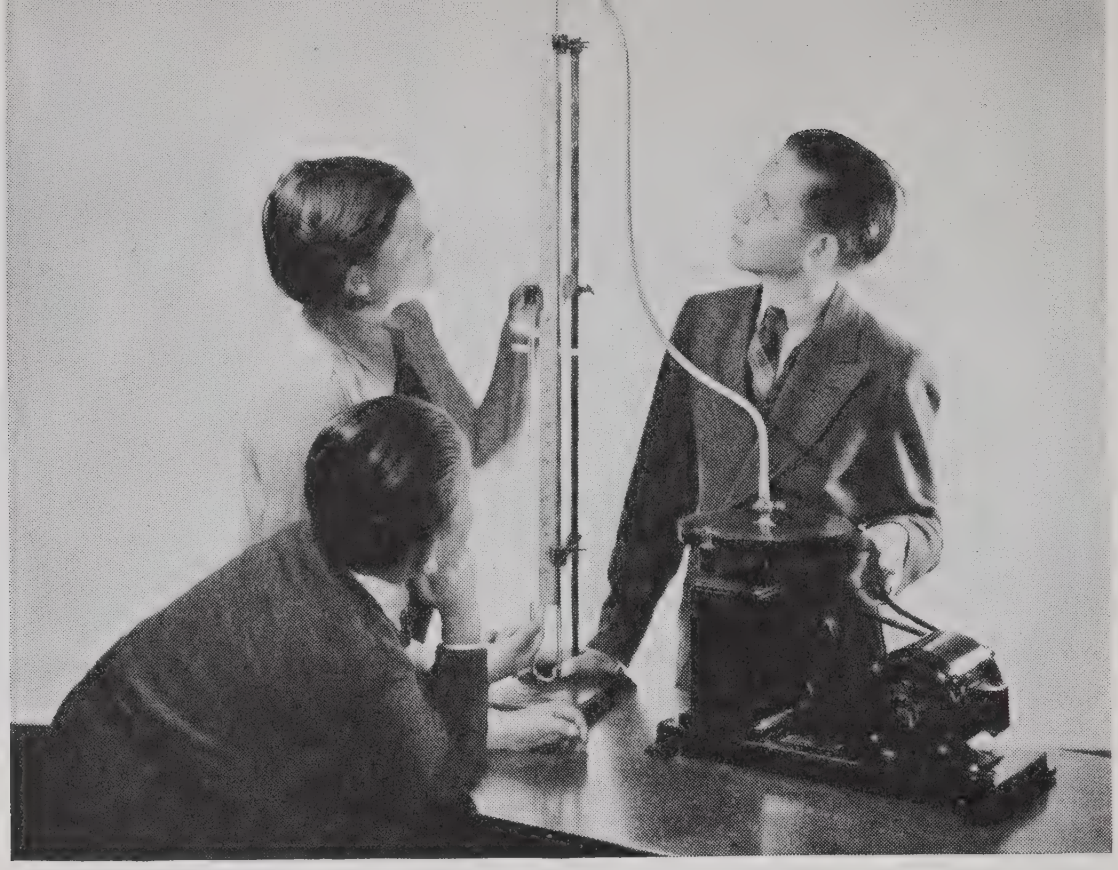


FIG. 81. A U-shaped tube with mercury attached to a vacuum pump

Problem 4:

HOW DO WE USE THE PRESSURE OF THE ATMOSPHERE?

HOW DO WE KNOW THAT THE ATMOSPHERE HAS PRESSURE? At some time or other you have used what we call "suction." You "suck" up milk and soda-water through straws, and pumps "suck" up water. Medicine droppers and fountain-pens are all filled by *suction*. You usually think that air, water, and other materials are "pulled" into places from which everything, including the air, has been removed, that is, into a *vacuum*.

In olden times people were sure that the suction was caused by a pull from the inside of empty spaces. Even the best of scientists in those days did not know what you already know—that air is pulled downward by gravity just as liquids and solids are. So of course they did not know that it is really the force of gravity that pushes things into an empty space.

Here is an experiment that you can imagine to help you understand what suction really is. You will probably

need to imagine the experiment because it requires a more perfect air pump than most schools can have. If you have a very good air pump in your school, you can actually do the experiment instead of imagining it.

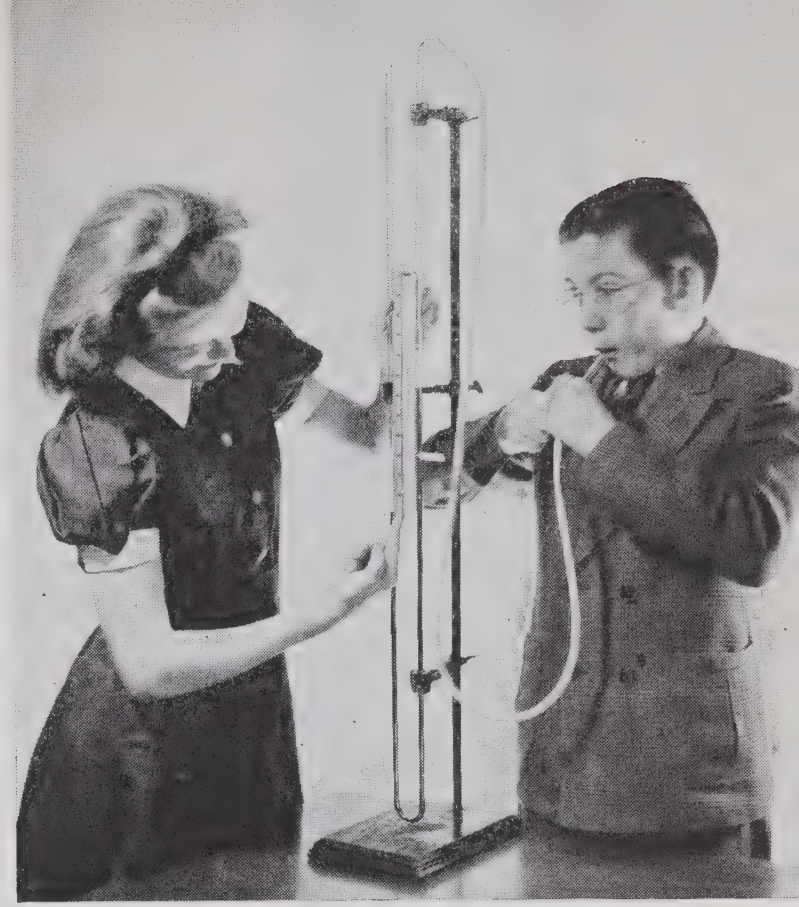


FIG. 82

To begin your experiment you will need a U-shaped glass tube about 50 inches long. Fasten the U-shaped tube in an upright position and pour in mercury until it stands about twenty inches deep in each side of the tube. This liquid metal, as you know, is very dense. A cubic inch of it weighs .49 pound, which is 13.6 times as much as a cubic inch of water weighs.

Now attach a thick rubber tube to one end of the U-tube. Put the open end of the rubber tube in your mouth and "suck" some of the air out. Can you guess what happens? The mercury rises a few inches in that side of the U-tube, but you cannot make it go up more than twelve inches (Figure 82). Try blowing instead of sucking, and you will find that you can blow the mercury up only about six inches above that on the other side.

Now attach the end of the rubber tube to an efficient vacuum pump instead of putting it in your mouth. As the pump removes more and more of the air from the tube, the mercury rises into the vacuum, rapidly at first, and then more and more slowly. Soon it comes to a standstill about thirty inches above the mercury in the other

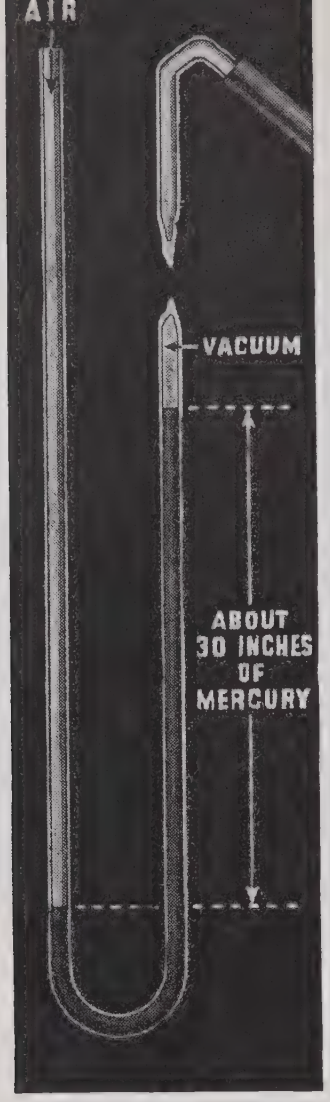


FIG. 83

side of the tube. No matter how long the pump runs, the mercury will not go higher. The pump has removed practically all the air from the tube; yet the "suction" apparently stops when the mercury reaches a height of about thirty inches. If you take a shorter tube, not less than thirty inches, or a longer one, the mercury will rise to the same height. If you pump the air from a straight tube that has the open end in a dish of mercury, the mercury will stop rising at the same height.

Let us continue the experiment. Take a Bunsen burner and melt the glass tube just below the rubber tube that goes to the vacuum pump. This will seal the tube so that no air can get back in. While it is still soft, pull off the useless upper end of the tube that is still connected with the pump (Figure 83). Each day measure the height of the mercury in the closed side of the tube. You find that the mercury moves up and down. On clear, cool days it is high. On warm, rainy days it is about an inch lower.

If you carry the U-tube up in the elevator of a high building, the mercury sinks in the closed side of the tube. As the elevator goes down, the mercury rises again. Surely there can be nothing in the vacuum that changes as you go up and down. The only satisfactory explanation of how the mercury acts is that the air pushing down in the open side of the U-tube holds the mercury up in the closed side.

Now, if you will think of the deep ocean of air in which you live, you can see why air has pressure enough to push the mercury up thirty inches although you can blow it up only about six inches. This ocean of air is certainly more than seventy-five miles deep. And gravity is pulling down on every cubic foot of air in that seventy-five miles! Even though the density of air seems very little to us, there is enough air straight above the open side of the U-tube to weigh as much as thirty inches of mercury in the closed side. The weight of the air above the open tube balances the weight of the mercury.

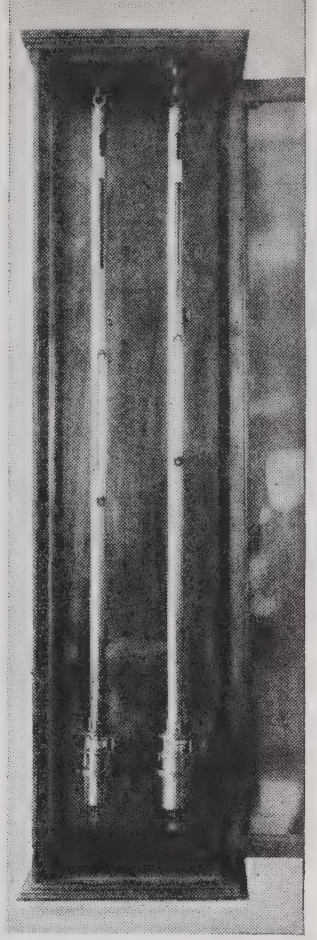


FIG. 84

HOW CAN WE MEASURE THE PRESSURE OF THE ATMOSPHERE? What you really have in your U-tube is a kind of automatic balance for weighing the air that is pressing into the open end. It is an instrument called a mercury *barometer* (pressure measurer). Of course, barometers that are sold by instrument companies are more carefully made (Figure 84), but they are only a little more accurate.

Mercury barometers are quite inconvenient to carry around; so inventors have devised a more convenient instrument called the *aneroid* (without liquid) barometer. The aneroid barometer is shaped much like an alarm clock (Figure 85). Inside the case is a cookie-shaped metal box with circular ridges on it. This metal box has had the air pumped out and has been sealed air-tight. A strong spring keeps it from being crushed by the atmosphere. As the air pressure changes, the sides of the vacuum box

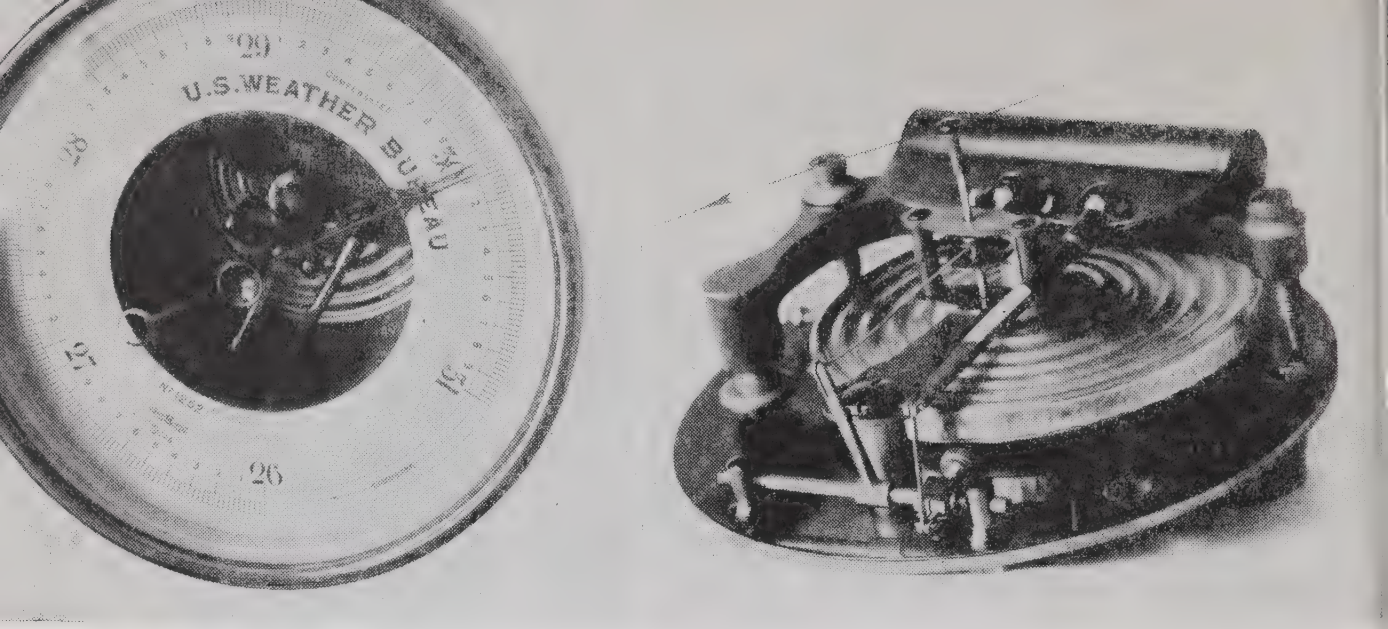


FIG. 85. The case and the inside of an aneroid barometer

move in or out. This motion of the sides of the box is carried to a pointer that moves back and forth around the face of the instrument.

Barometers are used by weather observers and by many other scientists who need to measure the pressure of the atmosphere. Mercury barometers are the most accurate kind, but some aneroid barometers are so sensitive that they show a change in air pressure when moved from the floor to a table. They are used by surveyors and mountain climbers to measure changes in height above sea level. The *altimeter*, by which an aviator tells how high he is flying, is an aneroid barometer especially made for that purpose.

WHY IS THE AIR PRESSURE DIFFERENT AT DIFFERENT HEIGHTS? In your imaginary experiment you noticed that the air pressure changed as you carried your barometer up and down in an elevator. Do you see why the air pressure changes? It changes because you are moving up and down through the air. In the can of water (page 91) you found that as the water got deeper, the pressure became greater. The same thing is true of the atmosphere. When you go up high, you have less air above you, and the pressure is less. When you go down low, you have

more air above you, and gravity makes the air press down harder on you.

Barometers carried to high altitudes fall to a reading of fifteen inches at a height of about three and one-half miles. This means that half of all the air in the atmosphere is within three and one-half miles of sea-level, although the atmosphere extends upward more than seventy-five miles. Most of the air is close to the earth's surface because air is easily compressed. The upper layers press down on those below and force the molecules more closely together. Ninety-five per cent of all the air is below a height of about thirteen miles.

Because the air is quite dense near the surface of the earth and thins out rapidly as one goes higher, flyers and mountain climbers have trouble reaching great heights. They cannot get enough air in their lungs to provide their bodies with the necessary amount of oxygen. Any climber who gets near the top of Mt. Everest, the highest mountain in the world, gets less than one-third as much air in his lungs with each breath as he does at sea-level. For this reason the men who try to climb this great mountain carry tanks of compressed oxygen to breathe when they near the top.

HOW HARD DOES GRAVITY MAKE AIR PRESS ON THINGS? You were born, you have grown up, and you have always lived at the bottom of the ocean of air that surrounds the earth. Your body has grown under the pressure of the air and has adjusted itself inside and outside so that you do not feel the pressure. Some simple experiments will show that air really exerts a great force on you and on everything around you.

EXPERIMENT 10. *What Will the Pressure of the Atmosphere Do to an Empty Can?* Put about an inch of water in a common

varnish can. Have a stopper ready to close the can air-tight. Heat the can until steam has come out of the opening for at least five minutes. The steam drives most of the air out of the can.

Remove the can from the heat, and, as quickly as possible, close the hole in the can air-tight. Pour cold water over the can to change the steam back into water. Explain what happens to the sides of the can.

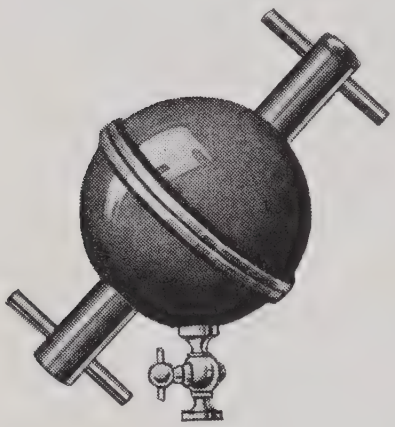


FIG. 86

One famous experiment is done with two metal half spheres, or hemispheres, which are now known as Magdeburg hemispheres (Figures 86 and 87). If you have a pair of these hemispheres in your classroom, you will want to see how they are used.

EXPERIMENT 11. *How Do Magdeburg Hemispheres Act When the Air Is Pumped Out of Them?* Examine the two hemispheres. Notice how they fit together perfectly at the edges. Notice the opening where the air can be pumped out of the joined hemispheres.

a) Press the hemispheres together tightly and see how easily they can be pulled apart.

b) Put them together again, and with your mouth suck as much of the air out as you can. Then see how much force is needed to pull them apart.

c) Repeat the experiment, using a vacuum pump to remove the air from inside the hemispheres.

To find out how great the pressure of the atmosphere is, think for a moment about the experiment with the air-pump and mercury in the U-tube. When the pump had removed the air from the tube, gravity was pulling the

FIG. 87. The experiment with the hemispheres was first done in 1650 at Magdeburg, Germany, by a scientist named Otto von Guericke. In one experiment his hemispheres were only twenty-two inches in diameter, but it took eight horses hitched to each hemisphere to pull them apart.

mercury downward in the vacuum side of the tube just as hard as it was pulling the air down in the open side. If you can find how much pressure thirty inches of mercury has, you will know how hard the air is pressing on the earth.

One cubic inch of mercury weighs .49 pounds. Thirty cubic inches piled on top of one another would press down with a force of $30 \times .49$, or 14.7 pounds. Thus, when the mercury in the closed side of the tube stands 30 inches above that in the open side, the air pressure is almost 15 pounds on every square inch of surface! Perhaps this may not seem to be a very heavy pressure. But think for a moment about the varnish can in Experiment 10.

A one-gallon varnish can is six inches wide and nine inches high. In one side there are fifty-four square inches

of surface. If the vacuum inside were perfect, each square inch would be pressed in with a force of almost fifteen pounds. Fifty-four times fifteen pounds is 810 pounds! When all the air is taken out of the can, the air is pressing against one side alone with a force of 810 pounds. On all four sides and the top the force of the air is 3780 pounds. No wonder, then, that the can was crushed!

In the famous experiment at Magdeburg (Figure 87) the teams of horses had to overcome a force of more than 5000 pounds on each hemisphere. On an ordinary window the air pushes with a force of from five to ten tons. The window does not break because the air is pressing with equal force on both sides. During high winds many windows are broken when the wind causes a slight difference in pressure on one side of the glass.

It seems quite surprising that such a light material as air can exert such a great pressure. But another little arithmetic problem will help you to see why the air can exert a great pressure. A cubic foot of air weighs about 1.2 ounces. A classroom 27 feet $\times$ 20 feet $\times$ 10 feet contains 5400 cubic feet of air. This would weigh 6480 ounces, or 405 pounds. A medium-sized auditorium contains more than a ton of air. When you remember that the earth is surrounded with a layer of air that is measured in miles instead of feet, you can easily see why this air presses with a great force on everything about us.

Self-Testing Exercises

1. What causes the mercury to go up in the side of a U-tube from which a vacuum pump has removed the air?

2. When a barometer is carried to the top of a tall building, does the mercury go up or down in the "vacuum side"? Why?

3. Describe two experiments which show that the atmosphere is pushing against things around us with a great force.

4. About how hard does the atmosphere push on a square inch of surface where you live? How is this force measured?

5. (*a*) What is an aneroid barometer? How does it work? (*b*) What advantages has an aneroid barometer over one that uses mercury?

6. What is an altimeter?

7. Why is the air at sea-level closely pressed together?

8. Why is it hard to get enough air to breathe at the top of a high mountain?

FIG. 88. An aviator with his oxygen mask and tank

Problems to Solve

1. In what way do you think the action of the mercury in the U-tube would be different if its rise were caused by a pull from the vacuum? Think first of exactly how the mercury acts: (1) It rises into the tube. (2) It stops rising at a certain height regardless of the length of the tube. (3) It moves slowly up and down as the air pressure changes. (4) It moves down as it is carried to higher levels and up again when it is returned to lower levels.

2. The face of an ordinary aneroid barometer (Figure 85) has numbers from twenty-six to thirty-one "inches." What do these numbers mean?

3. Mercury is 13.6 times as dense as water. How high would atmospheric pressure push water into a vacuum when it pushes mercury 30 inches?

4. What is the usual barometer reading in centimeters?

5. How many tons of air are there over a city lot 40 ft. x 125 ft. when the barometer stands at 30 inches?

6. How many tons of air are there over a city lot 40 ft. x 125 ft. when the barometer stands at 29 inches?

7. How is the action of the mercury in a mercury barometer different from that in a mercury thermometer?

8. How would the reading of a mercury barometer change if a little air should get into the space above the mercury? Explain why.

9. Will a mercury barometer indicate the correct air pressure if the tube is crooked or of uneven diameter? Give the reason for your answer.

10. What is the total force of the atmospheric pressure on the outside of a man's body if the area of the surface of his body is 18 square feet?

HOW DO WE USE ATMOSPHERIC PRESSURE? A great many everyday devices use atmospheric pressure. Let us see how some of these are constructed to make use of the pressure of the atmosphere.

EXPERIMENT 12. *How Does a Suction Cup Use Atmospheric Pressure?* Obtain a rubber sink pump or "plumber's friend," used to open up clogged sink pipes. Wet the edge of the rubber and press it tight against a smooth surface, such as a polished table top, a sheet of glass, or a slate blackboard. (Be careful not to break a window or blackboard in this experiment.) Some of the air inside the rubber cup is forced out under the edge of the rubber as you push on it. Now pull straight up or out on the handle. Explain why the rubber holds so tightly to the smooth surface.

EXPERIMENT 13. *How Does a Medicine Dropper Use Atmospheric Pressure?* Place the tip of a medicine dropper beneath the surface of the water in a tumbler. Press the rubber bulb of the dropper and then release it. Why does the water go into the dropper?

FIG. 89. How a sink pump is used for Experiment 12

The first step in using atmospheric pressure in any device is to make the air pressure less inside a closed space. When this is done, the weight of the atmosphere tends to force air or some other material into the closed space. This makes the device work as we want it to work.

You already know that air is composed of molecules that are moving at great speed. You also know that a football gets harder and harder as it is pumped up with air. Inside the football the molecules are striking the walls of the ball. Each molecule that strikes the wall gives the wall a little push. Since millions of molecules are striking the walls each second, you can see that the total outward push will be very great. The pressure of air in a football is, therefore, caused by the bombardment of molecules that push against the walls. To decrease the pressure of a gas inside a closed space, it is necessary to reduce the number of molecules that strike the sides every second.

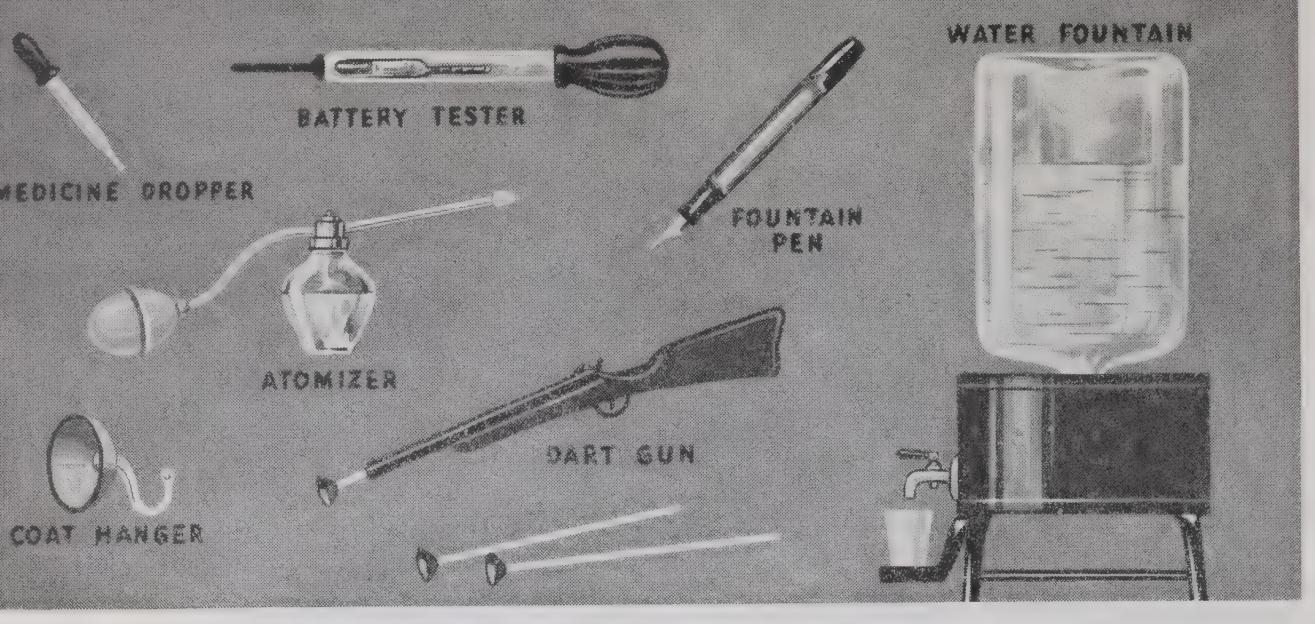


FIG. 90. These are some of the everyday uses we make of air pressure.

There are three ways to make fewer molecules strike the sides each second: (1) We can take out some of the gas. (2) We can enlarge the space. (3) We can cool the gas. Each of these three changes lowers the pressure in a closed space. This lowering of pressure inside a closed space is commonly called "creating a vacuum." (As you can see, there would not be a perfect vacuum unless all the molecules of gas were taken out. What is really produced, therefore, is a *partial vacuum.*)

In the case of the rubber "suction" cup in Experiment 12, you pushed some of the air out when you pressed it against the smooth surface. Then, when the cup was pulled back to its natural shape, there was less air to fill the space. This made a low pressure inside, while on the outside the full pressure of the atmosphere pressed against the cup. Since the air pressure is greater on the outside of the cup than on the inside, the cup was pressed, or held, against the smooth surface.

Ash trays and coat hooks are sometimes attached to automobile windows by the use of suction disks that work in this way. When the plumber uses the suction cup, he uses it to form a partial vacuum in the upper part of a sink pipe. Atmospheric pressure in the lower

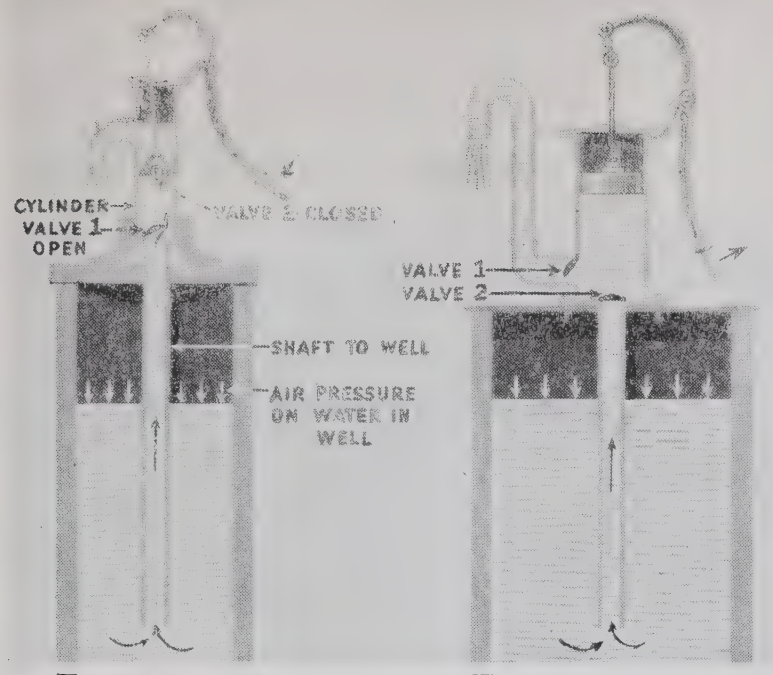


FIG. 91

FIG. 92

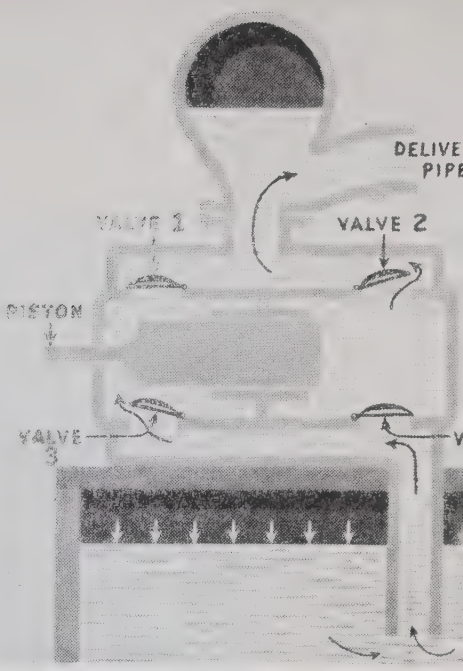


FIG. 93

Figure 91 shows a common lift pump; Figure 92 shows a force pump; and Figure 93 is a double-acting force pump. Tell how the valves work and how the water moves, (*a*) when the pump handle is pulled up, and (*b*) when the pump handle is pushed down. How does the double-acting force pump work, (*a*) when the piston moves to the right, and (*b*) when it moves to the left?

part of the pipe then pushes the water and dirt from the pipe up toward the sink.

Squeezing the bulb of the medicine dropper pressed air out of it. When the bulb sprang back to its natural shape again, the small amount of air left in it had a larger space to expand in; therefore it exerted a lower pressure. The pressure of the atmosphere on the surface of the water then forced the water up into the dropper.

Pumps that are placed above the water work in practically the same way as the medicine dropper. In the ordinary *lift pump* (Figure 91) the piston removes the air from the cylinder as it goes upward. The air in the pipe below expands into the cylinder through Valve 1. A valve of this kind is a little trap door that lets air or water go up but not down. When the piston starts downward, Valve 1 closes and keeps the air that has gone into the cylinder from getting back into the pipe. As the air in the cylinder is compressed by the piston, it pushes

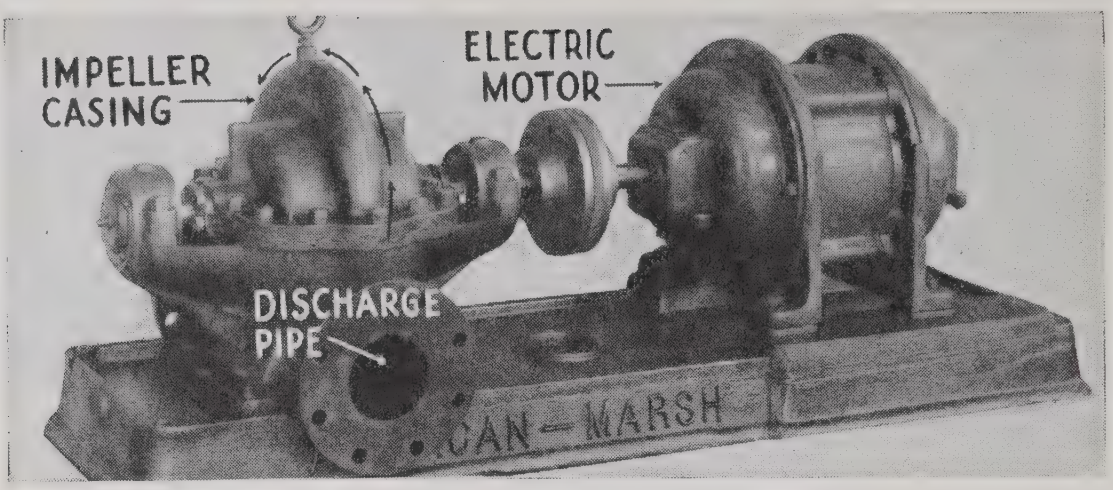


FIG. 94. A small centrifugal pump with the electric motor that runs it

Valve 2 open and escapes. More and more air is removed from the pipe by the pump as the piston goes up and down.

As the pressure inside the pipe decreases, the atmospheric pressure on the water in the well forces the water higher and higher into the pipe. Finally the water reaches the cylinder of the pump and is lifted out by the piston in the same way the air was removed at first. All such pumps work by removing the air from the inside of the pump so that atmospheric pressure will push the water into them. Then the piston pushes or lifts the water out of the spout. Sometimes the piston and valves of a pump become so worn that the pump is no longer air-tight. Then water is poured in to fill the cracks so that the air can be removed from the pipe. This is called *priming* the pump.

In the days of Galileo a nobleman had a pump put in a well that was more than forty feet deep. He was much disappointed when the pump would not deliver any water, although it was in good working order. Can you explain why water from the well did not reach the pump?

Think of the experiment in which all the air was pumped

out of the tube above the mercury (page 101). Atmospheric pressure would push the mercury up only about thirty inches. No amount of pumping would cause it to go higher. Atmospheric pressure can push water 13.6 times as high as it can push mercury. In other words, atmospheric pressure will force water up about thirty-four feet into a perfect vacuum. Even a perfect pump will not work if its cylinder is more than about thirty-four feet above the water that it is to pump. As a rule, pump cylinders are not set more than twenty-five feet above the water. Can you see why?

A different kind of pump, that is now widely used, is the *centrifugal pump*. You know how a whirling bicycle wheel or automobile wheel throws mud and water away from itself. The force that makes whirling things fly away from the center is called *centrifugal force*. A centrifugal pump uses this force together with atmospheric pressure to pump water. Figure 95 shows how this kind of pump works. It has a circular case in which a paddle wheel is made to spin very rapidly. The rapid spinning throws the air or water toward the outside of the pump and creates a partial vacuum in the center of the case. One pipe leads the air or water away from the outside of the case, and another pipe lets water into the center of the pump. Atmospheric pressure on the water around this inlet pipe pushes the water up into the pump. Since water is more dense than air, this kind of pump is often primed (filled

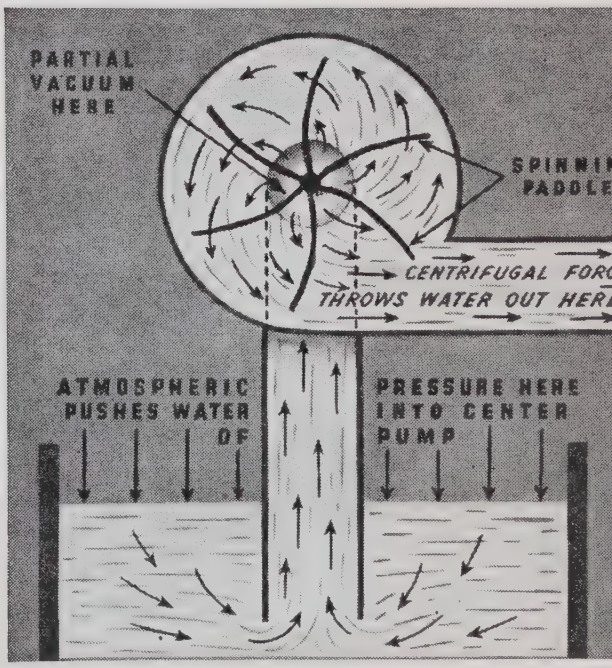


FIG. 95

with water) to make a better vacuum when the paddle wheel is first started whirling.

Centrifugal pumps can move water faster for their size than any other kind of pump. Some of the many places where centrifugal pumps are used are in automobile cooling systems, in city water-supply systems, on fire trucks, and in the basements of skyscrapers to fill the water tanks at the different levels in the buildings.

The vacuum-cleaner is another everyday machine that uses atmospheric pressure. If you do not know how vacuum-cleaners are made, the following experiment will show you how they work.

Experiment 14. *How Does a Vacuum-Cleaner Work?* Examine a vacuum-cleaner. Find the centrifugal fan that creates the partial vacuum. If possible, remove both the nozzle and the dust bag. Start the motor and test the force of the air at the inlet and at the outlet. Follow the path of the dust from a rug into the dust bag.

Inside the common electric vacuum-cleaner is a centrifugal air-pump driven by an electric motor. The paddle-wheel, or *rotor*, of this pump throws air out of its casing into a closely woven cloth bag. There is then a partial vacuum at the center of the pump. Atmospheric pressure forces more air in through the nozzle of the cleaner and into the center of the pump. When the nozzle is close against a rug carpet, or cushion,

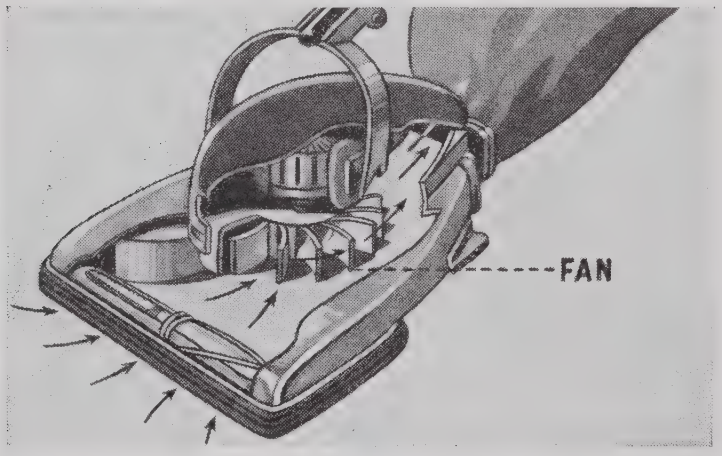


Fig. 96. The centrifugal fan in a vacuum-cleaner

the weight of the atmosphere forces air through the cloth and into the cleaner. The rapidly moving air carries the dirt and dust with it. The mixture of dirt and air passes through the cleaner and into the cloth bag, which catches the dirt and lets the air pass through. Many vacuum-cleaners have a revolving brush to help loosen dirt, hairs, and lint from rugs.

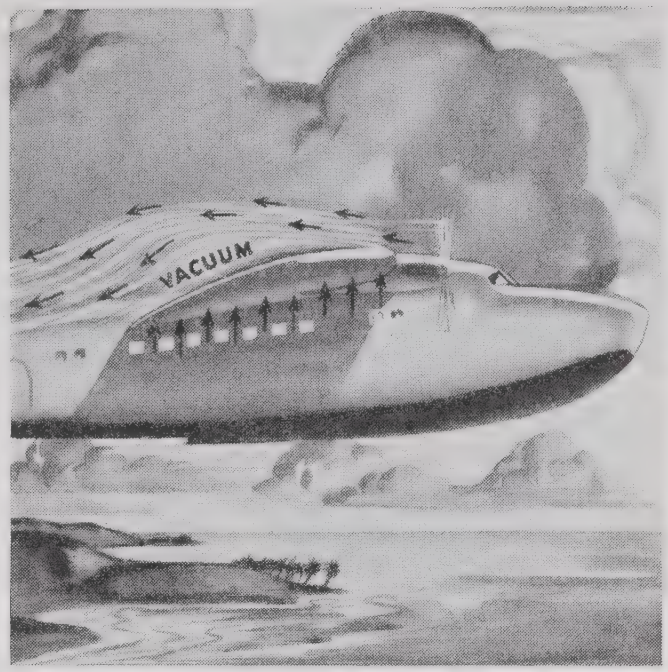


FIG. 97. How an airplane is supported

Atmospheric pressure helps drive and lift an airplane. As the propeller blades spin around, a partial vacuum or area of low pressure is produced in front of the blades. Back of the blades the pressure is greater; therefore the blades are pushed forward. But just as important is the shape of the wings (Figure 97). The wings of the plane are carefully shaped so that as they are moved forward through the air, a partial vacuum is formed on the upper side. Atmospheric pressure on the lower sides then holds the plane up.

Now let us see how all devices operated by atmospheric pressure are alike. In each of these devices there is some method of producing a partial vacuum; that is, of lessening the air pressure in or around the device. When this happens, the greater force of the outside air pressure pushes against the device or pushes against some movable part in it and makes it move.

Self-Testing Exercises

1. Explain how atmospheric pressure helps each of the following to work: (*a*) plumber's "suction cup," (*b*) medicine dropper, (*c*) a lift pump.

2. Why will a pump not work when its cylinder is more than 35 feet above the water?

3. How does a centrifugal pump work?

4. Explain how a vacuum-cleaner without a brush gets dirt out of a carpet.

Problems to Solve

1. Find as many things as you can that use atmospheric pressure. Make a list of them.

2. Ask your mother to let you open the next jar or can of fruit or vegetables. See if you can tell whether there is a partial vacuum between the lid and the contents of the jar. If there is, how would air pressure help seal the lid on a glass jar?

3. Fill a smooth-rimmed glass tumbler entirely full of water. Cover the tumbler with a square of stiff paper or cardboard so that it touches the rim at all points. Pick up the tumbler and quickly turn it upside down over a pan or sink. Why does the water not run out?

4. Lay a three-inch square of window glass or plate glass on a slightly smaller square. Lift the upper one. Does the lower one "stick" to it? Wet the two pieces of glass and again lift the upper plate. Explain the difference in what happens.

5. Why does the water or medicine in a medicine dropper stay in the dropper when it is lifted out of the liquid?

6. In deep wells the cylinder, valves, and piston of the pump are placed deep in the ground, and a long rod moves the pistons. Why is this arrangement necessary?

7. A swinging door moves inward when another door in the room is pulled outward quickly. Explain why.

8. Will an airplane "take off" more easily when the air pressure is high or when it is low? Explain your answer.

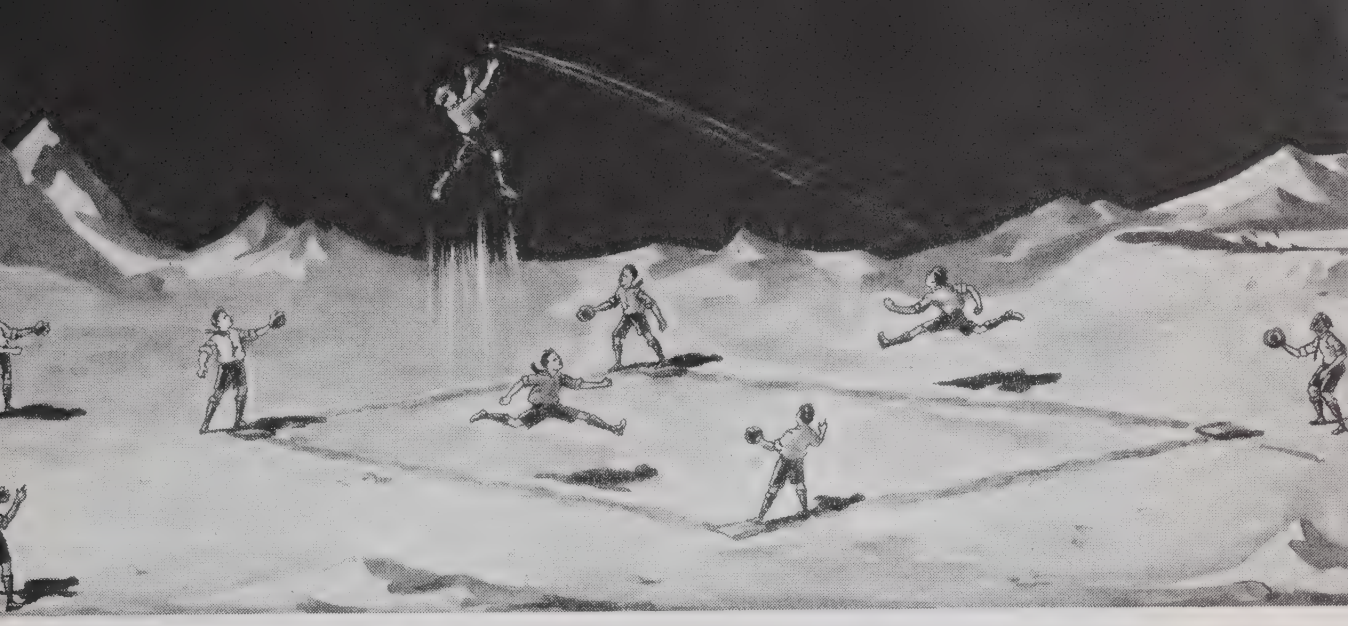


FIG. 98. A baseball game on the moon would be a strange affair. Three or four enormous strides would carry you from base to base. You could jump ten or fifteen feet into the air to catch the ball, and a hit would go so far that home runs would be easy to make.

Problem 5:

HOW DOES THE FORCE OF GRAVITATION DIFFER AT DIFFERENT PLACES?

MANY PEOPLE have been interested in the possibility of shooting a rocket to the moon. Scientists do not believe that passengers could arrive safely in such a rocket. Furthermore, visitors to the moon would have little or no atmosphere to breathe after they arrived. However, let us suppose that you and some friends can make the trip.

After having been cooped up in the rocket for several days during the journey, you welcome the chance to get out and move around. You feel strangely light on your feet. A five-pound box of candy you brought along for refreshments feels as if it were almost empty although it has not been opened. Someone suggests a jumping contest. A starting mark is made. The first boy runs as fast as he can and jumps. His strides seem unusually long, and, much to the surprise of everyone, he lands more than seventy feet away. On earth he has never jumped much more than twelve feet. "Gravity" is much less strong on the moon than on the earth. Why is that true?

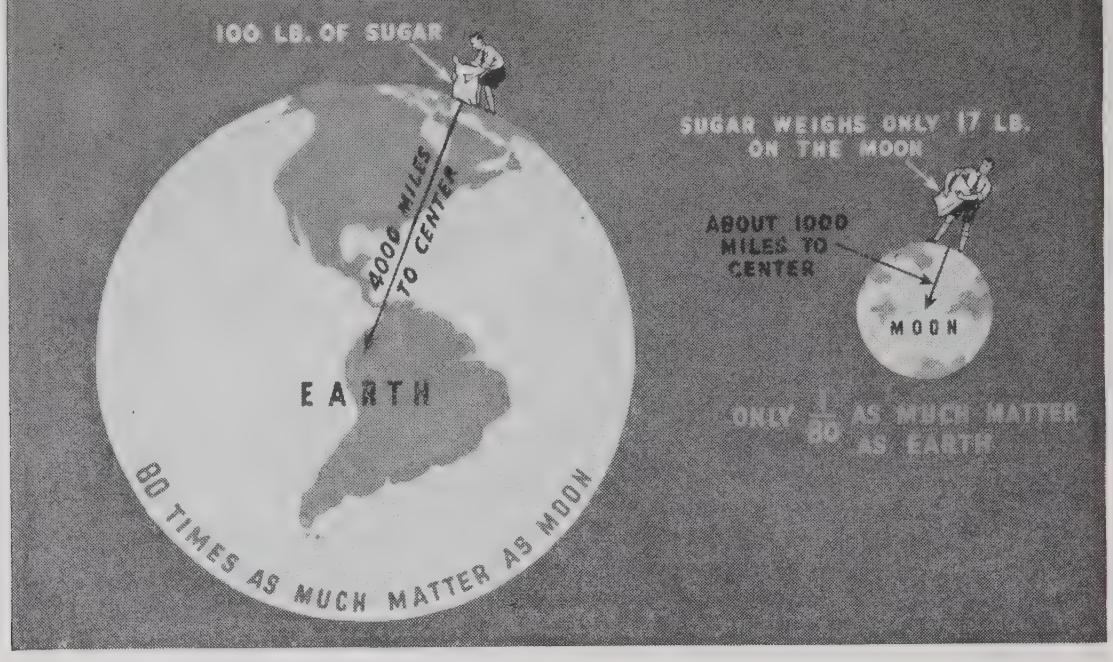

100 LB. OF SUGAR
4000 MILES TO CENTER
EARTH
80 TIMES AS MUCH MATTER AS MOON
SUGAR WEIGHS ONLY 17 LB. ON THE MOON
ABOUT 1000 MILES TO CENTER
MOON
ONLY 1/80 AS MUCH MATTER AS EARTH

FIG. 99. This diagram shows you the two important things that determine the pull of gravity on the earth and on the moon, namely, the distance to their centers and the amount of matter in them.

To answer this question you need to know two things. In the first place, the moon is much smaller than the earth. It has only about one-eightieth as much matter in it. Therefore, it will not pull as hard as the earth. You might expect to be held down only about one-eightieth as hard as on the earth. However, you need to know another thing: The closer the centers of two bodies are together, the harder they pull on each other.

Because the moon is much smaller than the earth, you would be much closer to its center than you can get to the center of the earth. This situation gives the matter in the moon about thirteen times as strong a pull as an equal amount of matter in the earth. That is, the pull of the moon on you would be about thirteen times one-eightieth, or about one-sixth, of your weight on the earth. If you weigh 100 pounds on the earth, you would weigh about seventeen pounds on the moon. You could carry two ordinary men around on your back.

If you continued your imaginary journey and visited the different planets and the sun, your weight would constantly change. On Mercury you would weigh nearly

twice as much as on the moon; your weight would be about thirty-one pounds. On giant Jupiter, however, you might have trouble walking; you would weigh more than 260 pounds! The heat of the sun makes it impossible for you to exist there, but that does not change the force of gravitation. At the sun's surface its gravitational attraction for matter is nearly twenty-eight times as great as that at the earth's surface. A boy or girl who weighs 100 pounds here would weigh nearly a ton and a half on the sun. You could not even lift an arm or a leg there! You would be as helpless as a jellyfish on land.

Even on the earth the gravity of a body changes a little as the body gets nearer to or farther from the center of the earth. The pull of gravity on a ton of coal (2000 pounds) is only about 1999 pounds when the coal is on a mountain two miles high. Because of the earth's spinning (rotation) on its axis, its surface is thrown out at the equator and pulled in at the poles. Thus any object at the North Pole is about thirteen miles nearer the center of the earth than it would be at the equator. Because of this a load of coal that is pulled by gravity with a force of 2000 pounds at the equator would be pulled at the North Pole with a force of almost 2011 pounds.

Thus you see that the gravitational force between two bodies, such as you and the moon, depends on three different factors: (1) how much matter there is in you, (2) how much matter there is in the moon, and (3) how far you are from the center of the moon.

Newton learned just how to calculate the force of gravity between bodies, and scientists since his time have used his Law of Universal Gravitation to solve many problems about the solar system. One of the most famous problems they solved was to find the cause of an irregular-

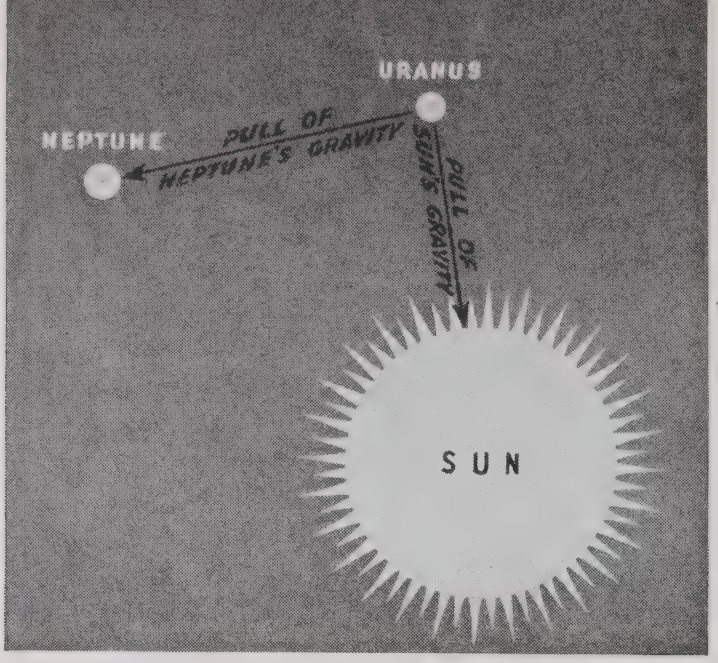


FIG. 100

ity that they noticed in the path of the planet Uranus. About forty years after Uranus was discovered, scientists noticed that it began to move farther from the sun than it should if it were being held in its orbit by the gravity of the sun.

Some astronomers suggested that there might be another planet still farther out than Uranus. The gravitational attraction of this undiscovered planet might be pulling Uranus out of its regular path (Figure 100). Careful calculations, according to the Law of Gravitation, showed where to look for the unseen planet if there was one. An astronomer turned his telescope in that direction, and in less than half an hour he discovered the planet Neptune. In calculating the paths of planets and comets and the times when eclipses occur, astronomers make constant use of this great law of nature.

Self-Testing Exercises

1. (*a*) State at least two unusual things you could do on the moon if you could go there and live for a few days. (*b*) Why could you do these things?

2. What three facts must be known before a scientist can calculate the gravitational force between two bodies?

3. Why is the earth's pull on a ton of matter not the same everywhere?

4. Why would a five-pound box of candy weigh nearly a pound on the moon, although the moon has only about one-eightieth as much matter in it as the earth has?

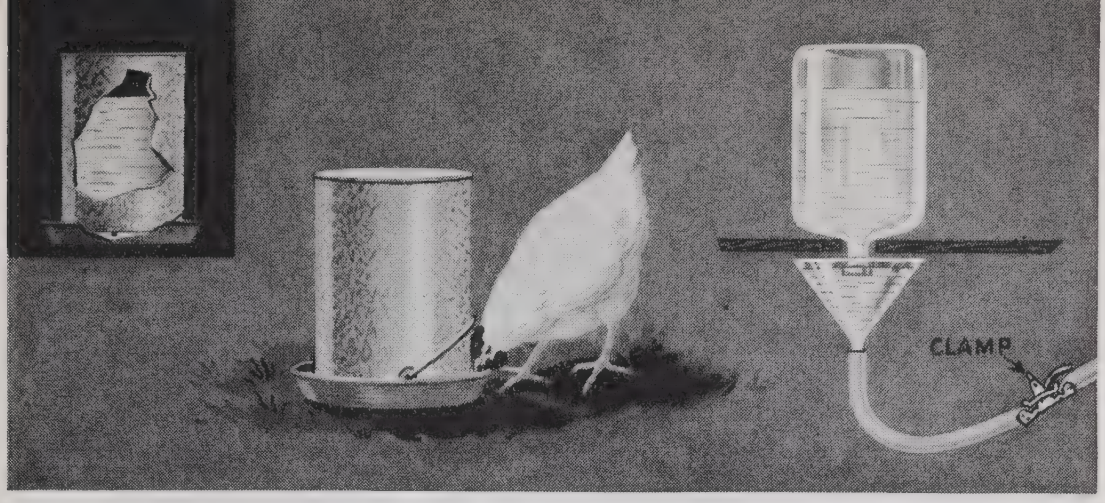


FIG. 101A. One kind of water fountain for chickens

FIG. 101B. Model of a water cooler

Problems to Solve

1. Imagine that you have taken some scales for weighing things on your trip to the moon. (*a*) What would you seem to weigh on scales that use weights and levers? (*b*) What would you seem to weigh on spring scales? Explain each answer.

2. Find Newton's Law of Universal Gravitation in a physics book or an encyclopedia. See how the law states the ideas you have been reading about.

3. Find in reference books the meaning of the word *mass*. What is the difference between the weight of an automobile and its mass? Which one changes? Which one stays the same?

LOOKING BACK AT UNIT 2

1. Turn to the Table of Contents. Copy the title of Problem 1 of Unit 2. Then answer it in a paragraph not more than one-half page long. Do the same for each of the other four problems of the unit.

2. Show that you know the meaning of each term:

gravity	*kilogram*	*atmospheric pressure*	*partial vacuum*
gravitation	*gram*	*centrifugal force*	*aneroid barometer*
altimeter	*density*	*barometer*	*scales or balances*

ADDITIONAL EXERCISES

1. A water fountain for chickens of the kind shown in Figure 101A uses atmospheric pressure. The can is filled with water and turned upside down in the pan. There are two or three holes near the edge of the can. Can you explain why the water fills the pan but never runs over the edge, even

though the can is full of water? A water cooler works on the same principle. A model of a water cooler (Figure 101B) will help you to see how the chicken fountain and the cooler work.

2. Prepare a report on "The Scientific Discoveries of Galileo."

3. Think up a way to use the small can in Experiment 8, page 88, to show that the pressure in water grows greater as it becomes deeper.

4. Otto von Guericke once made a water barometer. Tell how you could make such a barometer without an air pump.

5. Read about tides in reference books. Take notes of the most interesting things you learn and report to your class.

6. Get a small bell jar that has an opening at the top and place the jar on the plate of an air pump. Put a little vaseline on the edge of the bell jar so that it will stick tightly to the plate. Press your hand on the opening of the bell jar to make it air-tight; then have someone operate the pump. Describe the way your hand feels and tell why it feels that way.

7. Boil a small amount of water in a flask for three minutes. Remove the burner and quickly fasten the mouth of a rubber balloon over the mouth of the flask. Explain the results.

8. How does an atomizer use atmospheric pressure?

9. Set two similar vessels on a table. Fill one with water and connect the two with a glass or rubber tube filled with water. Have the tube reach to the bottom of each vessel. Such a tube is called a *siphon*. When does the water stop running into the vessel that was empty at first? After the water has stopped running, place a brick or a wooden block under one vessel. Does the siphon start again when you fill it with water?

10. Sink a glass jar in a large pan of water until the jar is completely filled with water. Turn the jar so that the bottom is up and lift it until the mouth of the jar is almost to the top of the water. Does the water run out of the jar? Explain.

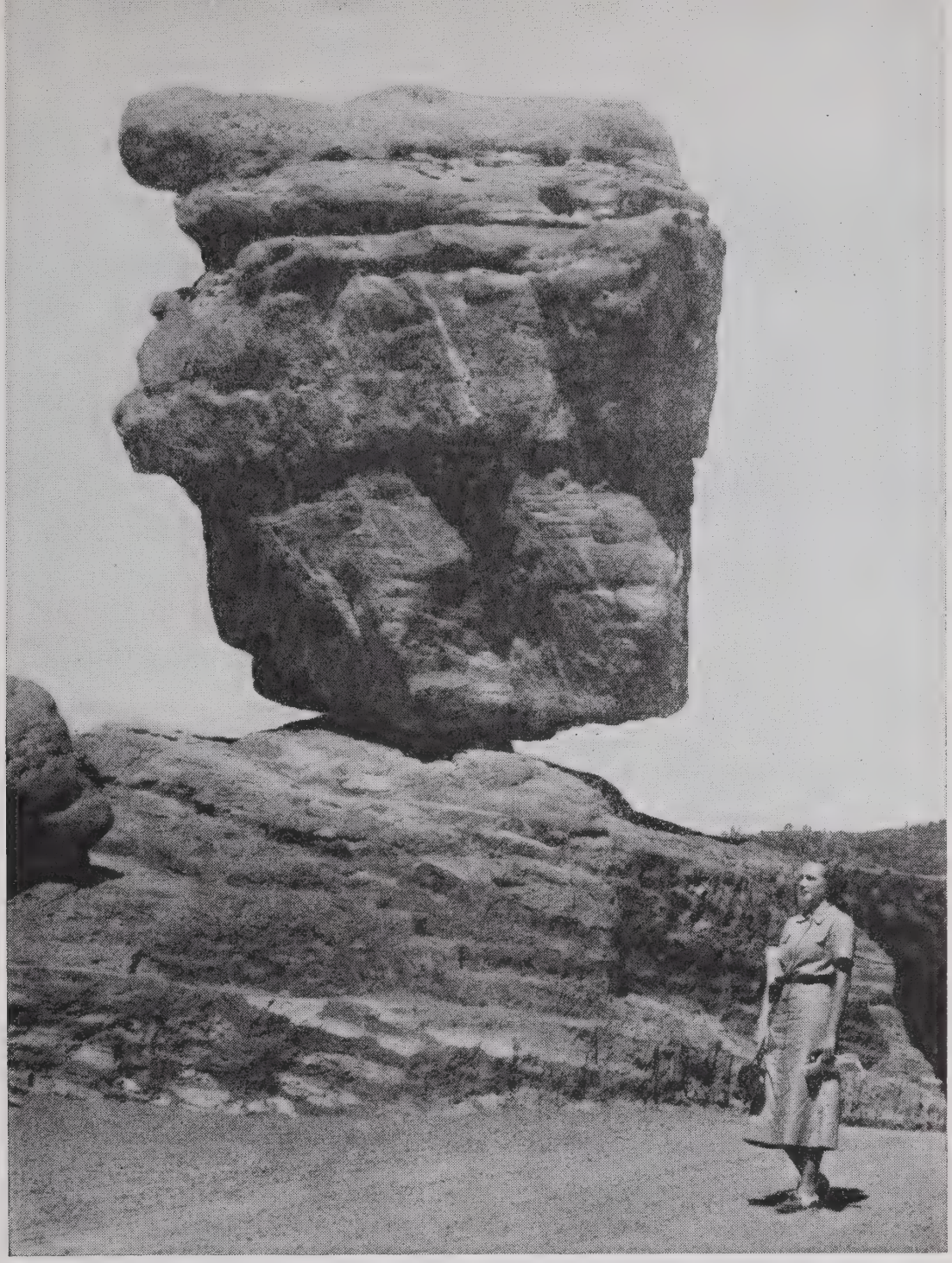


FIG. 102. This strange rock formation, called Balanced Rock, is in the Garden of the Gods, Colorado. For hundreds of years wind has blown sand against the rock, wearing away the softer parts and leaving the harder parts in this peculiar shape. Sometimes the entire face of a cliff may be worn away into curious shapes. In this unit you will learn about the different forces that are at work constantly to cause changes in the earth's surface.

UNIT THREE

UNIT 3

HOW DOES THE EARTH'S SURFACE CHANGE?

INTRODUCTORY EXERCISES

1. Except for the oceans, most of the earth's surface is soil. What is this soil made of? Explain briefly.

*2. How may a chemical change make a material different from what it was before? List as many differences as you can think of.

*3. When a solid such as rock or glass is heated, does it expand or contract?

4. Name three ways in which materials that make up the earth's surface are moved from one place to another. Which of these ways do you think is most important in making the earth as it is today?

5. Name as many ways as you can in which plants change the surface of the earth.

*6. What is a solution? How does the ability of water to dissolve materials help to wear away rock?

7. How do geologists know that water has covered most parts of the earth at some time in the past?

8. What is lava? How do you think it is formed?

9. What is a flood plain? Why are flood plains often very fertile?

10. Have mountains that we see today always looked the way they do now? Explain.

11. What is erosion? Why is it important to many farmers?

12. How is the surface of the earth changing in your locality at the present time? Make a list of the ways.

13. How are great caves in the earth, such as Mammoth Cave, formed?

FIG. 103. Do you know that the surface of the earth changes in some way every day? It will be different tomorrow than it is today. Some of these changes take place so slowly that we cannot see them. But many of the changes made by water are visible to us day by day. The picture above shows how hard rains, moving swiftly down the slope, have carried away soil and have cut deep gullies into a hillside that was once smooth.

LOOKING AHEAD TO UNIT 3

A GROUP of men were sitting in front of a store in a small town. It was a hot day in summer, and everything seemed very dull and uninteresting. Finally a young man said, "I wish something would happen around here. Nothing ever does. If I could come back to this place a thousand years from now, I believe I'd still recognize it. Not a thing would be changed."

"I'm not so sure of that," said an old man sitting near. "I've been here for sixty years, and I've seen a great many changes in this short time. Even the land seems different! When I came here as a boy in 1876, the place was mostly in woods; and in the fields that were cleared the soil was rich and black. No one ever thought of fertilizing his crops. Later, most of the trees were cleared away, and the drainage canal was dug. Soon the surface soil began to wash away, and gullies began to form. One

FIG. 104. In 1926 Lake Como, in Houston County, Minnesota, was as you see it here—a beautiful lake around which a popular summer resort grew up. Just ten years later it looked as you see it in Figure 105. See if you can think of some reasons for this rapid change before you read the legend beneath Figure 105.

of the finest houses in the village stood where Black Creek now runs through the western part of town."

"Well, that is hard to believe," said the young man. "Black Creek is about fifteen feet deep."

"But it's true," was the old man's reply, "and a great many other changes have taken place. You know that big swamp just below town? That swamp was once a lake. Now it has filled up until it is only a foot or two deep. So many changes have taken place since I've been here that I'd not be able to recognize it as the same place."

People often think, as the young man did, that the earth does not change. But scientists can easily prove to you that the surface of the earth is really changing all the time. Some changes happen quickly. For example, in a few hours or days a great flood may change the course of a river. Or the flood may deepen the channel of the river in one place and leave sand-bars where there were none before. An earthquake may make great changes in

FIG. 105. Here you see Lake Como as a swamp through which a small stream moves slowly. This may be explained by the fact that soil which is carried away from one place, where it belongs, must be deposited as sediment in another place, where it does not belong. That is, soil that has been carried away from a hillside, like that in Figure 103, may pour into a lake in such quantities that the lake is filled up with it.

a few seconds. About a hundred years ago a great earthquake was felt in western Tennessee. Afterward it was discovered that an area of land eighteen miles long had been lowered, and water had poured in to form a lake. This was named Reelfoot Lake.

Other changes take place so slowly that even the *geologists* (scientists who study rocks) are not sure that these changes are going on. For example, geologists are fairly sure that a range of new mountains is rising in the western part of the United States, but several generations may come and go before we can be certain that this change is taking place.

Have you ever wondered how the soil and rock, the valleys and lakes, and the plains or mountains near your home were formed? In this unit you will learn about the kinds of changes that have been going on in your own neighborhood for many millions of years.

Problem 1:

HOW ARE ROCKS CHANGED INTO SOIL?

WHAT IS the earth's surface made of where you live? Is it nearly all soil or nearly all rock? For almost everyone the answer to that question is, "Soil." The parts of the earth where people live must have soil to grow plants for food. But if you dig down into that soil far enough, you will always come to rock. This rock that lies under the soil is called *bed rock*. Scientists tell us that everywhere the surface of the earth was once rock of some kind. How can hard rock change into soil? Let us first find out what soil is.

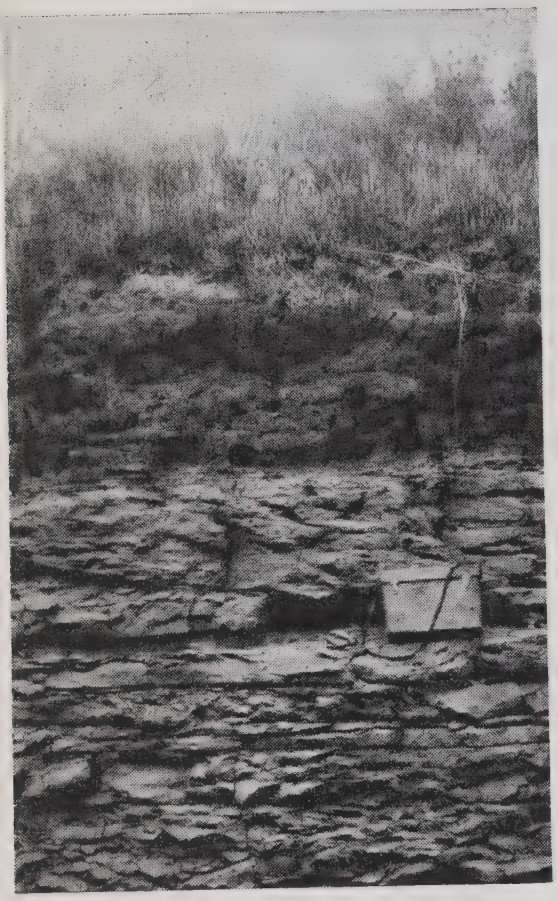


FIG. 106. Bed rock may be far down under the soil, or it may be very near the surface of the earth.

WHAT MATERIALS IS SOIL MADE OF? The best way to begin your study of soil is to examine the soil itself. Have you ever looked at this material carefully to see what it is like?

EXPERIMENT 15. *What Are the General Characteristics of the Soil Where You Live?* Study the soil near your home to a depth of at least three feet. Arrange the results of your observations in the form of a table.

a) At a depth of about four inches make the following observations: (1) What color is the soil? (2) What is its general consistency; that is, is it sticky or crumbly, loose and porous, or closely packed and hard? (3) Are there any stones in it? If so, are they like the bed rock, or are they of a different kind? (4) Are there any plant roots in the soil? (5) Are there any ants or earthworms in the soil?

Take a sample of the soil with you for further study in the classroom.

b) Repeat part *a* at a depth of eighteen inches.

c) Repeat part *a* at a depth of three feet.

How is the soil different at different depths? Is the soil different at different places in your locality?

EXPERIMENT 16. *What Materials Can Be Recognized in Soil?* (*a*) Put about two inches of soil from Experiment 15*a* into a clear glass jar or a glass cylinder at least six inches deep. A deeper jar is better. Add water until the jar is almost full. Stir the water and soil or close the jar and shake it until the soil particles are completely separated from each other and thoroughly mixed with the water. Allow the mixture to stand undisturbed for a day.

Notice what kind of material settles first, what settles last, and what remains suspended in the water or floating on top. Compare the materials that settle as to color, size of particles, etc. If you can, repeat this experiment with samples of soil from other depths and localities. Compare the results you get with the different kinds of soil.

Allow the jars from this part of the experiment to stand undisturbed for use in Problem 2.

b) Put a small amount of dry soil on a piece of glass or white paper. Examine the soil with a magnifier (and with the low power of a compound microscope, if you have one). Look for sand particles, dark decayed vegetable material, and lighter clay (or mud). Clear glass-like particles with either sharp or rounded corners are probably grains of *quartz*, or true sand. The decayed plant material is called *humus*. Clay is so fine you cannot see the particles with a magnifier. It settles out of water very slowly.

With the magnifier look through the glass at the soil that has settled to the bottom of the jars in part *a*. Estimate the per cent of sand, clay (or mud), and humus in the samples you are studying.

FIG. 107. Particles of clay are tiny and stick together tightly when they are wet. When a clay field dries out, it becomes hard and cracked. Because clay gets very hard, it is baked for a long time at high temperature to make building stones and pottery.

c) Put a very thin layer of the soil from the four-inch depth in a "tin" can lid and heat the lid red-hot over a burner. Does the soil blacken for a time and then change to a lighter color, especially after it has cooled? This change in color is caused by the plant material, or humus, in the soil. The humus burns, leaving only the mineral matter in the soil.

If you did the experiments carefully, you probably found that the upper soil was darker and looser than the soil at a depth of one, two, or three feet. The deep, lighter-colored soil is called *subsoil* by farmers. Usually plants do not grow so well in it as they do in the upper ten inches of soil. Can you think of a reason for this fact? You probably found, too, that most samples of soil are made up chiefly of sand, of clay that makes mud when it is wet, and of decayed and decaying plant material called humus, or *organic material.* "Organic "means that the material was once part of a living thing.

Each of these three materials is needed in soil if plants are to grow best. Pure sand is very loose and porous. If you pour water on a pile of sand, most of it runs right

FIG. 108. The farmer is loosening up the sandy soil of a blueberry field with a harrow. Certain other crops, such as melons, sweet potatoes, peanuts, and sugar-cane, grow well in sandy soil. However, sandy soil is often too dry for some crops.

through. Sand contains very few minerals that can dissolve and be used by growing plants. When it is mixed with humus and clay in soil, sand tends to make the soil loose and easy to cultivate. But soil that contains too much sand dries out quickly.

Clay often contains minerals needed by plants; also, it will hold a great amount of water. However, it packs tightly together and dries out slowly. If clay is cultivated when it is wet, it becomes almost as hard as brick when it dries.

Humus, however, improves both sand and clay. It holds sand together and also helps it to hold moisture. It makes clay looser and easier to dry and to cultivate. As humus decays more and more, it provides minerals needed by plants. It also produces chemical substances that help to dissolve the useful minerals in clay. Fertile soil, that is, soil in which plants grow well, must contain decaying plant material.

As you study your locality, you may find some loose soil that is mostly sand. It probably contains enough

clay and humus to make plants grow well if they receive plenty of moisture. Such a soil is called *sandy soil.* You may also find some compact, poorly drained soil that is mostly clay with some humus and little sand. Cotton and corn may grow well on some *clay soils.* In general, however, clay soils are poor for farming.

FIG. 109. Quartz is one of the most abundant minerals. Besides being found as small grains in sand, it is found as large crystals. Each crystal has six sides, each side going to a point.

The third kind of soil that you may find is called *loam.* Loam contains about fifty per cent of sand mixed with almost equal parts of clay and humus. Thus loam has some of the desirable characteristics of each of these three materials. It is, in general, the best kind of soil. Of course, not all soils fit perfectly into these three types. People who study soils find many kinds. In general, however, soils are classified as sandy soils, clay soils, and loams.

From your study of soil you now know that soil contains sand or clay or both mixed with decaying organic material, or humus. Where do the sand and clay come from? Sand is made up of fine grains of a substance called *quartz.* Quartz is a mineral found in many rocks. It is a chemical compound composed of one part of the element silicon and two parts of the element oxygen. The chemical formula is SiO_2. Quartz is so hard that a steel knife will not scratch it. When rocks containing quartz are gradually destroyed, the quartz is broken into

smaller and smaller pieces. It is finally left as the sand we find on beaches, in sand-bars, and in soil.

Rocks contain many minerals besides quartz. Almost all of these other minerals form very fine mud or clay when the rocks are broken up and destroyed by nature. The sand and clay in our soil, therefore, come from the destruction of rocks. The kind of soil found in any place will depend on the kinds of rocks that were changed into the soil and upon the amount of humus that has been formed and mixed with the sand and clay.

Self-Testing Exercises

1. What is soil? Why is soil very important to you?
2. What are the three important materials found in soil?
3. How is subsoil different from top-soil? In which kind of soil do plants usually grow better?
4. Name the three general kinds of soil and give two characteristics of each.
5. What is humus? Of what value is it in soil?
6. What is clay? Where does it come from?

Problems to Solve

1. Classify the samples of soil from Experiments 15 and 16 as sandy soil, clay soil, or loam.
2. Get a quart or more of each type of soil—sand, clay, and loam. Plan and carry out an experiment that will show which kind of soil will hold most water.
3. Plan an experiment to find fairly accurately the amount of sand, of clay, and of humus in a sample of soil. Experiment 16*c* may give you an idea for testing the amount of humus.

HOW ARE ROCKS CHANGED CHEMICALLY BY AIR AND WATER? You have learned that rock changes into the sand and clay that we find on the earth's surface. But that stone door-step of your home hasn't changed a

bit since you were old enough to notice it! And the stone walk in grandfather's garden has been there since he was a little boy. The stones that you know do not seem to be changing.

But you must remember that these changes take a long, long time! And there have been millions of years for rocks to change. Let us see if we can find some rock that nature has been changing.

Experiment 17. *How Does Stone That Has Been Exposed to Water and Air Differ from Protected Stone?* Get a number of different stones from the soil, from streams, and from other places near where you live. Look especially for some that seem to be soft and "crumbly" on the outside. You may even wish to crack a corner off one of the pieces of an old stone walk or wall if no one will care.

With a knife try to scratch the outside of one of the rocks you have collected. Notice its color and hardness. Then lay it on a large rock or piece of metal and break it with a hammer. Test the center of the broken stone as you did the outside. Is the center like the outside, or has the outside been changed in some way by its exposure to water and air? Examine other pieces in the same way. Have some changed more than others? If so, can you think of reasons for the differences?

Many pieces of rock have a different color and are softer on the outside than in the center. The outer parts of some can be flaked or scraped off very easily. Of course, there are great differences because the rocks are of different kinds, and some have been exposed to the weather longer than others.

The changes that we have noticed are mostly chemical changes. They are caused by water, carbon dioxide, and oxygen. Most kinds of rocks are formed deep in the earth. As soon as they are exposed to moisture and air, chemical

FIG. 110. This cliff of solid rock is being broken up gradually. Did you ever see a cliff like this with broken rock at the bottom? How did the rock become broken off into smaller pieces?

changes begin to destroy them. Most of the chemical substances or minerals in rocks are changed into new materials. Quartz is one substance that is changed very little by chemical action. Some of these new materials from the rocks form clay. Others are dissolved and carried away by water. These changes soften the rock and make it easier to wear away. The chemical changes that destroy rock are caused by the action of air, rain, and sun; therefore they are often spoken of by scientists as the *weathering* of the rock.

But chemical changes are only part of the changes that after a time destroy all rock that is exposed to the air. Let us see what other kinds of weathering can affect the rocks of the earth.

HOW ARE ROCKS BROKEN INTO SMALL PIECES? Look at the picture on this page. Notice the pile of broken rock at the bottom of the solid rock cliff. Notice also how the rock of the cliff is split. Such cliffs are very common. An experiment will show you one way in which big rocks are broken into smaller rocks.

FIG. 111. Rocks, like glass, crack when some parts of the rock expand and contract more than other parts.

EXPERIMENT 18. *How Do Expansion and Contraction Break Rocks?* (*a*) Obtain a strip of ordinary window glass about six inches long and three inches wide. Almost any piece of broken glass several inches long will do. Hold one end of the glass in the flame of a gas-burner for a few moments. What happens?

b) Heat a piece of glass tubing until it is quite hot. Then plunge it into some water. What happens to the glass?

The glass broke in the experiment because not all parts of it were heated and cooled equally. One part of the window glass became hot and expanded more rapidly than other parts. This made the glass break. The glass tube was cooled on the outside by the water, but the inside stayed warm. Therefore, as the glass cooled, the outside contracted faster than the inside, and cracks were made all through the tube. Some kinds of rock are cracked in much the same way. When they are heated on the outside by the bright sunlight, the outer part expands faster than the inside, and pieces break off. In other rocks very tiny cracks appear because of heating and cooling. These cracks gradually become deeper and larger.

Cracks in rocks allow both water and air to enter. As you have learned, water and air cause chemical changes that soften the rock. Because of these cracks, weathering goes on inside the rock as well as on the outside.

When water runs into a crack and freezes, it makes the cracks wider. An experiment will show you how this happens.

EXPERIMENT 19. *How Does Water Act When It Freezes?* Fill a bottle completely full of water. Do not allow any bubbles to remain. Wire a stopper in the bottle tightly or tighten the screw cap as much as you can. Put the bottle in the freezing compartment of an electric refrigerator, set it outdoors on a cold night, or bury it in a mixture of three parts of crushed ice with one part of salt. What happens to the bottle when the water freezes?

From this experiment you can see how water in rocks expands with a tremendous force when it freezes. Thus the freezing of water that has trickled into the cracks in rocks helps to break the rocks into smaller pieces.

The third way in which rocks are broken up is by plants. Plants send their roots into the cracks in rocks. Then, as the roots grow, they force the rocks apart and often break them into smaller pieces. Plants and animals also help in the chemical weathering of rock. Growing roots give out chemical compounds that dissolve away the surface of some kinds of rock. Chemicals from decaying plants also soften rocks. Ants, earthworms, and larger animals that burrow in the soil allow water and air to get down into the soil around rocks. These animals also bring bits of rock

FIG. 112. There are several trees growing out of this rock. As their roots grow larger and larger, they split the rock until it breaks into pieces.

FIG. 113. Wherever moving water runs over stones or beats against them for a long time, the stones are rounded off and smooth like the ones shown in this picture.

to the surface, where the effects of heat, cold, and rain can wear the rock material down more rapidly.

The fourth way in which rocks are broken into pieces is by the action of moving water, wind, and ice. As you will learn later in this unit, water, wind, and the ice of glaciers rub pieces of rock together and grind them into fine rock powder that soon becomes soil.

Now you have learned how the earth was changed and is changing from solid rock to soil. Rocks, when exposed to the sun, rain, and wind, are changed by a process that is called weathering. Water, oxygen, and carbon dioxide may change them chemically into softer substances. Expansion and contraction during changes of temperature and the freezing of water in cracks break the hardest of rocks into pieces. Plants and animals also help to change the rocks.

Rocks are worn down when they are ground together by moving water and ice. Wind-blown sand cuts rocks to pieces. In these ways all kinds of rocks are changed into the sand and clay that cover much of the earth's surface. When plants die and decay, they add their own

substances to the soil each year. These substances become mixed with the materials from rock and thus make the soil a better place for other plants to grow.

Self-Testing Exercises

1. How can you tell when a rock has been changed by chemical weathering?
2. Give two ways in which changes of temperature can cause rocks to break.
3. Name three ways in which plants help in the formation of soil. Explain each one briefly.

Problems to Solve

1. List the ways in which a piece of rock you find in the soil may be different from a piece of the same kind of rock that has just been taken from a stone quarry.
2. Make a list of all the ways in which the air helps to destroy rocks.
3. Why are we sure that rocks change into soil, even though we cannot notice the rocks changing from year to year?
4. Write a brief description of the earth as it might be if rocks could not be broken up or changed into soil.
5. Read in reference books about quartz and other common minerals, such as feldspar and mica. Find how each one may be recognized.
6. Why is it possible to find several kinds of soil in one locality?
7. Give a reason why farmers sometimes plow under a crop of clover or rye and mix it with the soil of their fields?
8. Collect different kinds of pebbles from as many different places as you can. Try to decide how each pebble has been shaped. That is, was it shaped by running water, by waves, by a glacier, or by weathering?
9. Which ways of changing rock to soil have been most important in your locality?

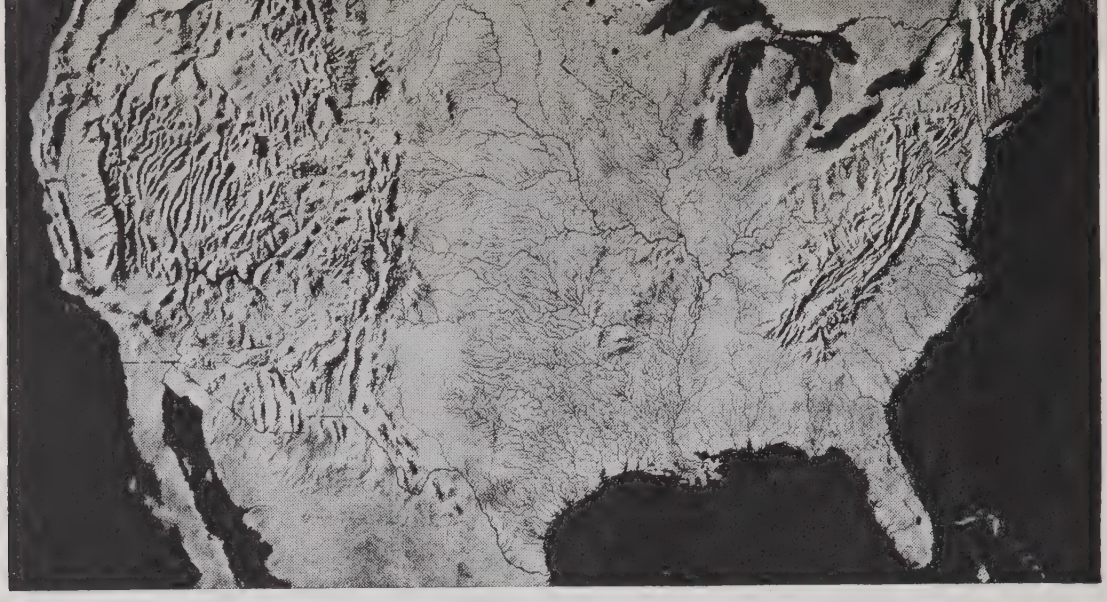


FIG. 114. On this relief map of the United States you can see how many small streams flow together to make the Mississippi River. Because gravity pulls all matter downhill, the water in all of these streams is moving soil down to the ocean.

Problem 2:

HOW ARE MATERIALS CARRIED FROM PLACE TO PLACE?

WE THINK of the Panama Canal as one of the great engineering feats of the world. Government engineers spent ten years moving 240,000,000 cubic yards of material to make the canal. That amount of material would fill all the freight cars in the United States four times! Yet, impossible as it may seem, in nine months time the Mississippi River alone carries more material into the Gulf of Mexico!

Over a large part of the northern United States scientists have found a layer of soil, clay, and rock that was not formed there. It came from somewhere else. Scientists have learned that great glaciers moving down from the north in the long ago smoothed off the hilltops and filled in the valleys from Canada to the Missouri River and the Ohio River and from the mountains of the West to the Atlantic Ocean. These glaciers brought many cubic miles of rock, clay, and sand and covered up the valleys and level ground. In some places they left a layer that is 500 feet deep. Surely transportation is "big business" with nature!

We use wagons, railway trains, trucks, automobiles, and airplanes to transport things. Nature uses only water, wind, and ice. And the force that moves all three of these is gravity! You can easily see how gravity pulls pieces of broken rock to the foot of a steep cliff. You can see how gravity makes rain fall and streams run down to the sea. You can see how gravity forces glaciers to move downward through mountain valleys. Later you will find that gravity also makes the wind blow.

Let us now see how these great transportation agencies of nature do their work.

HOW DOES MOVING WATER CARRY MATERIALS? After a heavy rain, you can always see where the rain water has picked up soil and small stones from one place and left them in another. The water cuts little gullies in every bank that is not well protected with grass. Little sandbars are left along the gutters and ditches. Little "fans" of soil and gravel are spread out on sidewalks and in other places where the water runs slowly or forms pools. You can see the same thing in every plowed field that is not perfectly level. In the low places you can find spots where the water has dropped its load of material. All these things you can see after any heavy rain.

The study of nature shows us that there are general rules or laws that help us explain the things we see happening. What are some of the rules that water follows in carrying materials?

One of the simplest rules followed by water is the result of the pull of gravity. Water, as it flows over the surface of the earth or through spaces within the earth, moves downward. Therefore it is a general rule that *materials carried by water are moved to lower places.*

A second rule of transportation by running water is

FIG. 115. Because flood water moves rapidly, it carries large quantities of material—rocks, soil, trees, etc. As the water spreads out over fields and towns, it gradually drops the material it is carrying. This picture shows the pile of soil and rubbish left in a street after a flood.

almost as simple as the first: *The amount of material that water can carry depends on how fast the water is moving.* The faster water runs, the more material it can carry. It may even roll large stones. Whenever water slows down, it must drop part of the load it has picked up.

During or after a heavy rainfall, you can see how the rule works. In places where the land slopes, little grooves and gullies are made in the soil as the water flows rapidly down the slope. The mud and gravel moved by the water are left on level ground and in the ditches where the water slows down. Materials that are being carried by the water are said to be *suspended* in the water. Or they are said to be *in suspension.* They are called *sediment.*

A third rule is closely tied up with the second rule: *Water sorts the materials it carries.* It sorts the materials into large and small pieces because it can carry large pieces only when it is moving rapidly. When it begins

FIG. 116. Each year new land is made around the edges of these islands in the Mississippi River. The land is made from the soil that the water carries down the river and drops on the islands as it moves more slowly.

to slow down, it first drops the largest pieces. A little farther along, as it moves more slowly, it drops smaller pieces. The fine mud will not settle until the water has been perfectly quiet for a time.

Look at the soil in the bottom of the jars in Experiment 16*a*, or repeat that experiment with a large jar and a mixture of small gravel, sand, and clay. As soon as you stopped stirring the water, the gravel went to the bottom. Then, as the water became more and more quiet, finer and finer materials settled. Only after a day or more did the finest mud settle. Geologists can usually tell when they find materials that have been carried by water; such materials have been sorted according to size and weight.

Running water also carries materials that it has dissolved. Rain water that falls on the soil dissolves some kinds of minerals from soil and rock and carries the minerals away into near-by streams. As you know, the par-

ticles of dissolved materials are too small to be seen, and they cannot be filtered from the water. Thus, water that has been filtered through much sand and soil may be perfectly clear and yet be carrying minerals *in solution.* The amount of minerals carried in solution at any time is usually not large, but over a long period of years water will dissolve and carry away great amounts. Furthermore, the parts of the soil that will dissolve are the parts that are most useful to plants.

But, as you know, not all the rain water flows off into streams. Some of it soaks into the soil and stays there for long periods of time. We call this part of the water *ground water.* Gravity pulls the ground water downward through the soil and the crevices in the rock until it reaches a layer of clay or rock that it cannot get through. The water gathers above this layer of material and fills all the tiny spaces in the soil and rocks.

As the ground water moves slowly down through the soil and rocks, it dissolves many substances. Some of the minerals will dissolve in pure water. Others will not dissolve in water alone, but they will dissolve in water that contains some other substance, such as carbon dioxide. For example, limestone is almost entirely a white mineral called calcium carbonate ($CaCO_3$). This mineral does not dissolve easily in pure water. But carbon dioxide dissolved in the water changes the calcium carbonate into another compound, called calcium bicarbonate, that dissolves rather easily. The carbon dioxide to cause this change comes from the roots of plants and from decaying plants in the soil.

Water from deep wells and springs sometimes is salty or tastes and smells "like rotten eggs." Such water in seeping through the earth has gone through salt or miner-

als that contain sulphur compounds, and has dissolved them. Some well water leaves rust-colored stains where it drips slowly or evaporates. These stains are caused by iron compounds that have been dissolved in the water and are left as the water evaporates.

You have now learned that water picks up material and moves it in solution, in suspension, and by rolling and sliding it along. Working in these ways, water is the greatest excavator on the surface of the earth.

Self-Testing Exercises

1. State and explain three simple rules that water follows in moving materials.

2. Name two ways in which water carries materials. Give an example of each way.

3. Limestone is made almost entirely of calcium carbonate, which will not dissolve in pure water. Why is ground water able to dissolve some of the calcium carbonate?

Problems to Solve

1. Where in your neighborhood are materials carried away during a heavy rain?

2. One boy who explored several streams in a hilly region noticed that there was a deep place in the stream bed below each waterfall. Which rule of transportation by water explains how this hole was formed?

HOW DOES WATER DIG VALLEYS AND CAVES? Before you can begin to answer this problem, you will need to have clearly in mind the meaning of a word often used by geologists. This word is *erosion*. You have learned that rock is gradually destroyed by weathering; that is, water, ice, and wind slowly wear away the hardest of rocks. You have also learned that water picks up materials from the high lands and carries them with it on its

way to the sea. All this wearing down and carrying away of the rocks and soil is called erosion. As you will soon see, erosion is very important to all of us.

Almost every one carries in his mind the picture of some great river valley that he has seen or of some small stream valley that he has explored. Many years ago people had queer explanations of how these valleys were formed. Some believed that they were made by earthquakes that opened cracks in the earth. They thought that after the valleys had been formed, water collected in them to make streams. Gradually scientists came to see that the stream that flows in almost every valley has itself dug the valley. They learned how to read the history of valleys, and they discovered many strange and interesting facts about them.

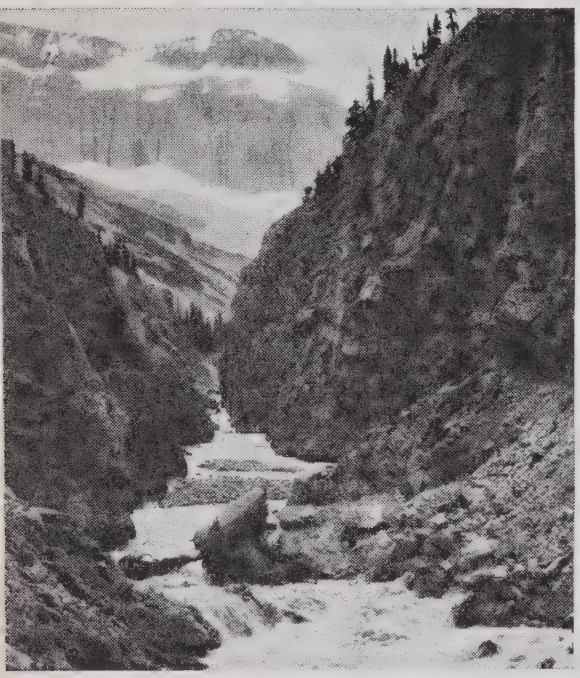


FIG. 117. A young valley is deep and narrow at the bottom. At the top, where the banks are washed away, it is wider.

A valley begins as a narrow groove in the earth. If the stream runs rapidly, the water cuts deeper and deeper. So long as the stream is cutting deeper, its valley remains narrow with steep sides. Usually we can say that it is a V-shaped valley, and it is called a *young valley*.

Later the stream stops cutting downward so rapidly because the valley becomes more nearly level, and the water flows more slowly. The water then begins to swing from side to side in the valley as it moves along. This cuts away the banks and widens the bottom, or *floor*, of the valley. Such a valley has a U shape and is called a *mature valley*.

FIG. 118. Gradually the rough places and the steep sides of a young valley are worn away by the rains and the streams until it becomes a wide, gentle valley.

But the water does not stop digging even though the valley has become mature. The water of the stream will continue to widen the valley and carry away material until the slope of its sides becomes very gentle. By that time the water runs so slowly that it cannot carry much sand, clay, or other materials. A wide valley with very gentle slopes is known as an *old valley*.

The history of a valley seems quite simple. But do not expect to see some young valley change into a mature one in a few years, or a mature valley become an old one during your lifetime. These changes take hundreds or thousands of years. However, you can see how the valley of a small stream develops. First, go up to the source of the stream. There you will probably find a small, steep-sided ditch or gully cutting back into poorly drained land. By following the stream downward, you can see how the other parts of the valley become wider and wider, with the sides less and less steep.

The surest place to find young valleys developing is on rolling or hilly farm land. There during thousands of years soil formed, as you learned in Problem 1. Plants

FIG. 119. This airplane view shows an area in Nebraska where rains have washed the rich soil from the fields and cut deep gullies. Millions of acres of good farm land in the United States have become useless for growing crops because water has been allowed to carry away the rich top soil.

and trees grew in the soil. The small plants and the fallen leaves kept the soil from being washed away because they stopped the water from running rapidly down the slopes. But farmers came and cleared away the forests. Even the grass was plowed up so that corn, wheat, tobacco, and other crops would grow in the loosened soil.

Now every rain that falls on those farms carries away great loads of rich soil. You can see it in the water of every creek and river after a rain. The water cuts young valleys or gullies farther and farther into the fields. If the farmer does not stop the action of the water, in a few years all the rich soil is gone, and the fields are rough and useless. They are abandoned, and nature begins again her slow formation of good soil.

This loss of good soil by erosion is one of the great problems our country faces today. Farmers must learn to leave the steeper parts of their farms in forest or grass. They must learn to manage their fields so that every rain does not steal the best soil. Later on in your science

study you will learn about some of the things that are being done to save the soil of our country.

Look at the picture on this page. Does it show you another way in which water cuts away and carries away the soil? Waves driven by the wind break against the shores of oceans and lakes. Soil is carried away. Sand and gravel are soon dropped to form beaches and bars along the shore. During storms the material torn away by the waves may be piled up behind the beach in a ridge that later waves cannot reach. The fine humus and clay remain suspended in the water for a long time and finally settle in quiet water. Along rocky shores the waves drive the loose rocks against each other and against the solid rock. In this way the rock is gradually ground to pieces and carried away.

Have you ever visited Mammoth Cave, Kentucky, or some of the other great caves in our country? If so, you probably know how those caves were made. Strange as it may seem, those caves were made by water. Let us see how water can dig miles of caves in solid rock.

Such caves are found only in regions where the rock underneath the surface is limestone. As you have already

FIG. 120. For thousands of years moving water has slowly cut deeper and deeper into rocky banks of lakes and oceans, grinding the rock into bits. When the action of waves can cut into solid rock like this, you can imagine what it does to soft earth.

FIG. 121. This is the Natural Bridge in the Shenandoah Valley. Some natural bridges have been formed when the top of a large cave fell in, leaving part of the roof. The part of the roof that was left formed the "bridge."

learned, water containing carbon dioxide in solution can dissolve the calcium carbonate of which limestone is made. Water from the surface of the land seeps down through tiny crevices in the rock and begins to dissolve and carry away the stone. The opening gets larger and larger until a cave is formed. Through millions of years such great caverns as Mammoth Cave in Kentucky, Luray Caverns in Virginia, and the Carlsbad Caverns in New Mexico have been produced. Sometimes the water dissolves out a funnel-shaped pit in the rock, or the roof of a cave falls in. The soil above these holes settles, and a low place in the ground is formed. Such a low place is called a *sink hole*.

You have now seen that the chief kinds of erosion by water occur in the formation of valleys, the cutting away of shores by waves, and the dissolving of limestone to form caves and sink holes.

Self-Testing Exercises

1. How are valleys usually formed?

2. How can you tell the difference between a young valley and a mature one? Between a mature valley and an old one?

3. Why is erosion a serious problem in the United States?
4. How do waves carry on erosion?
5. Explain how caves are formed.

Problems to Solve

1. Imagine that you can go to the source of some stream at the head of a young valley and travel in a few minutes to the ocean through older and older parts of the valley. Tell how the valley would change and what special features you could see as you went along.

2. Is erosion of farm land serious in your locality? Notice the land itself if you can. Also ask questions of farmers and others to solve this problem.

3. Are the valleys in your locality young, mature, or old? Or are all types found there? Name examples and give reasons for your answer to this problem.

4. Find out what the government is now doing to help farmers prevent erosion on their farms.

WHERE DOES WATER DEPOSIT THE MATERIAL THAT IT CARRIES? You already know that sediment, such as mud and sand, carried by a stream settles where the water slows down. In young valleys the water runs swiftly along; therefore very little eroded material is dropped. However, in a mature valley the stream runs more slowly. The river forms many curves that gradually widen the floor of the valley. During floods the water spreads over the whole wide valley bottom. Because it runs slowly in the wide space, some of the clay and humus settles on the floor of the valley. This level space that is covered by water when the river overflows its banks is called a *flood plain.*

Usually flood plains are fertile farm land because from time to time they receive new deposits of soil that has been washed off the high ground. The flood plains of such

FIG. 122. At the sides of the slow-moving Susquehanna River are wide, level flood plains. They are formed when the flood waters spread out, slow down, and drop the heaviest load of soil that they have carried from higher places.

rivers as the Nile in Africa, the Ganges in India, and the Yangtze in China are noted for their rich land. Great centers of civilization have developed on each of these plains because the rich soil made it easy to grow enough food plants to feed large numbers of people.

But most of the mud and sand carried by a stream never gets out on to the flood plain. In old valleys the water is often flowing so slowly that the material is deposited right in the stream bed. This is especially true of our own Mississippi River. Through much of the river's length the land slopes so gently that the water flows slowly; therefore, soil is always settling to the bottom of the river. During floods much of the material is again picked up and carried away.

In places where there are small obstructions in the river, the current is slowed down even more, and more soil settles here. So sand bars and mud bars begin to form

FIG. 123. Along the Mississippi River, from Cairo, Illinois, to New Orleans, Louisiana, there are dikes. These are big banks of earth, sometimes thirty feet high. You can see that a dike is a necessary protection here, because the river is higher than the land along it.

around these small obstructions. When the river is low, trees and other plants grow upon this soil, and the roots hold the soil in place. During floods more soil is deposited among the plants until large islands are formed. In recent years at Memphis, Tennessee, a huge island, called Mud Island, has formed near the water-front, where Wolf River flows into the Mississippi. This island is a great hindrance to the boats that carry freight and passengers up and down the river.

At many places in the Mississippi the government spends much money keeping channels open for steamboats. The government engineers usually apply their knowledge of our second rule of stream erosion. They build *dikes*, or banks, that force the wide river to flow in a narrower channel. Then it must flow faster, and it can pick up and carry material. Thus the river deepens its own channel.

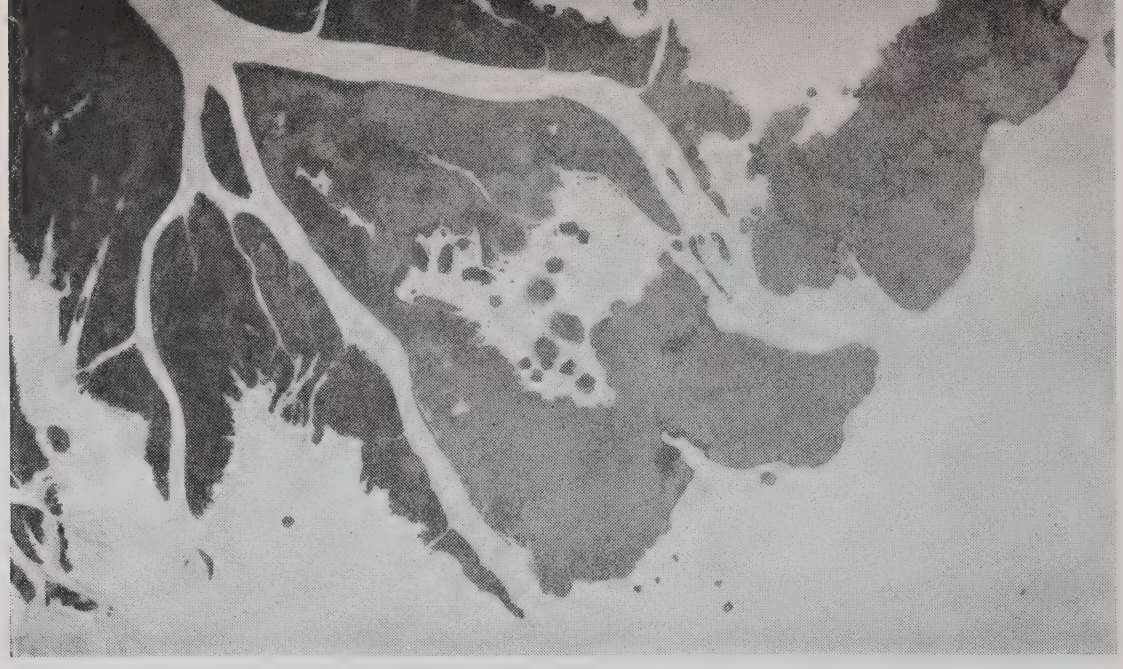


FIG. 124. From an airplane a part of the Mississippi River delta looks like this view. The delta reaches more than 200 miles out into the Gulf of Mexico. The river is continuing to push its delta on outward at the rate of about 340 feet each year.

When a river reaches the ocean, the flow of its water is checked by the quiet ocean water. Then its load of sand and mud settles to the bottom. The material that is dropped builds a *delta* out into the ocean. Many famous rivers have built deltas, on which great cities have grown up, surrounded by rich agricultural lands. One of these deltas is at the mouth of the Nile. Here stand the great cities of Cairo and Alexandria. On our own continent a long narrow arm of the Gulf of Mexico once extended all the way to the mouth of the Ohio River. The Mississippi River has filled that whole arm of the Gulf.

But not all the material carried by water is suspended so that it can settle. Dissolved material can be deposited only when the water evaporates or some chemical change occurs. Water that has been seeping through the limestone of cave roofs drips from the roof and runs down the sides. When the water comes out into the air of the cave, some of the dissolved carbon-dioxide gas escapes. Then the water can no longer keep the lime (calcium carbonate) in solution. The lime is deposited in layers on the sides of

FIG. 125. In the Hanging Garden, Great Onyx Cave, Kentucky, lime is deposited both in the form of stalactites and of stalagmites.

the cave and in great icicle-like forms that hang down from the roof. These hanging deposits are called *stalactites*. Where the water drips on the floor of the cave, deposits called *stalagmites* are built up. When a stalactite and a stalagmite meet one another, a *column* is formed.

However, the greater part of the minerals in solution is carried into streams and finally into the ocean. A smaller part is carried into lakes and seas that have no outlet into the ocean. The water, held in these great basins, is constantly evaporating. The minerals cannot evaporate. As more and more water brings in its load of minerals, the solution becomes stronger and stronger. Through chemical action some of the minerals change to solids and settle to the bottom. Others are used by sea animals to build their skeletons and shells.

Common salt and some other minerals tend to remain in the water; therefore the water is very salty in the ocean and in lakes that have no outlets. If a great body of salt water dries up completely, the salt and any other minerals that are in the water are left on the bottom. Rock salt is believed to have been formed in some such way through the repeated filling and evaporation of a basin of salt

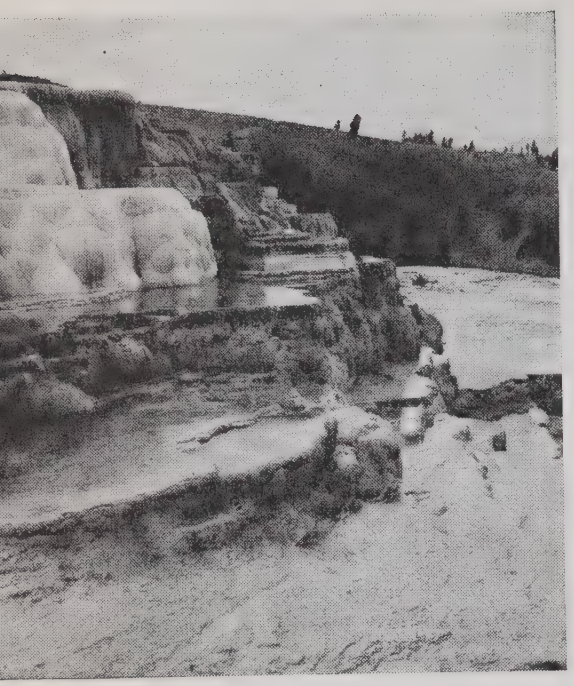


FIG. 126

water. Rock salt more than 2000 feet thick is found under parts of Louisiana. In Germany some of the deposits of salt are as much as 5000 feet thick.

One of the most interesting and beautiful features of Yellowstone Park is the mineral deposits around the hot springs and geysers (Figure 126). Scientists believe that the water is heated by hot volcanic rock beneath the earth's surface. Hot water can dissolve greater amounts of minerals than cool water. When the hot water comes up out of the earth, it cools, and part of it evaporates; the minerals change back to solid form and are left in many shapes and colors.

As you hike or travel or read, look for examples of materials deposited by water. The sand and gravel in bars, on the beach, and in sand and gravel "pits" have been left there by moving water. The rich soil of flood plains along rivers and deltas at the mouths of rivers has been transported by moving water. Beautiful caves and hot springs, salty oceans, and salt mines would not exist if water could not carry dissolved minerals.

Self-Testing Exercises

1. Tell how each of the following is formed: flood plain, mud island, delta.
2. What is a stalactite? How is it formed?
3. Why are thick deposits of minerals formed around hot springs and geysers?
4. How does the ocean become salty?
5. How do dikes help keep rivers from getting shallower?

FIG. 127. Curious shore formations result from the movement of waves upon shores. Material drifted by waves often builds up long, narrow hook-shaped bits of land, called *spits*.

Problems to Solve

1. Where have you seen deposits of material left by water? Make as long a list of places as you can.
2. Plan an experiment that you might carry out in a garden to show how water erodes and deposits material.
3. Where would you expect to find the greater number of gravel-bars, in the young part of a valley or in the old part of a valley? Why?
4. How are *natural levees* formed? Consult reference books to find the answer to this problem.
5. How is erosion helpful to farmers who are growing crops on flood plains?

HOW DOES MOVING AIR CARRY MATERIALS? Have you heard of the terrible dust storms that swept over parts of the United States a few years ago? Great clouds of dust formed in the West and were blown across the country and out over the Atlantic Ocean. In Tennessee and Virginia there was at times so much dust in the air that the rain water was muddy. In February, 1934, a queer brown snow fell in New England. Chemists found that it was brown with a kind of soil that is found in Oklahoma, Texas, and Kansas. That single "snowstorm"

FIG. 128. In many parts of our country there have been terrible dust-storms. Strong winds have drifted thousands of tons of soil over fields, fences, and buildings, and have brought ruin to the farmers who had cultivated the soil.

dropped over thirty pounds of western soil on each acre of a large part of New England.

The places where this dust came from became almost a desert. The farmers had plowed land that was covered with grass and had planted other crops in the bare soil. Then came several dry years. There was not enough moisture to hold the soil together. Millions of tons of the farmers' richest soil were lifted high in the air by strong winds and carried across the country. Thus, if wrong methods of agriculture are used in regions where little rain falls, or if our climate changes only a little, so that the amount of moisture decreases, the rich soil on which our food depends is carried away by the wind.

Have you heard of *sand dunes?* Wind can move material to form dunes only in places where there is little moisture and where there are few plants to hold the soil. The dunes are formed of sand, because wind sorts materials much as water does.

Wind does not have force enough to move pebbles and stones. It lifts the fine soil from the land and carries it far away to settle in a thin layer over the earth. Then it blows the sand along the earth's surface and piles it up

FIG. 129. These are sand hills near Yuma, Arizona. Strange stories are told of how huge moving sand dunes cover up roads, trees, and homes and uncover them years later. Sometimes in desert regions ancient cities have been found covered by sand dunes.

in great drifts that we call dunes. Along the shores of lakes and oceans the sand has already been sorted out by the water and washed up on the beach, where the wind can pick it up as soon as it is dry.

Wherever a plant or other object slows the moving air, some of the sand forms a small drift. Then more and more sand is blown against the drift, rolls up the front of it, and settles behind, until a dune is formed. The wind continues to blow the sand up the face of the dune and drop it behind the dune. Thus a dune may move along, covering up trees and buildings in its path, and uncovering them again later.

In places where there is much rain, dunes finally stop moving and become stationary. Plants begin to grow on them, and new soil is formed. Finally the dunes may become covered with trees. Along the southern shore of Lake Michigan are some of the highest dunes known. There the wind has picked up the beach sand and made hills that stand over two hundred feet above the lake (Figure 130).

Geologists tell us that the winds were at work moving soil in the past just as much as they are now. Along the

FIG. 130. Some of the dunes along the shores of Lake Michigan are composed of dry moving sand, while other dunes have become stationary and are covered with thick forests of oak trees.

Mississippi River valley and in certain parts of China geologists have found beds of fine soil hundreds of feet thick that were left there by the winds of long ago.

Self-Testing Exercises

1. What are the two most important causes of the dust storms that did so much damage in western Kansas a few years ago?

2. Tell how a sand dune gets started and what may stop its movement.

HOW DO GLACIERS CHANGE THE EARTH'S SURFACE? When scientists began to study the land in the northern part of the United States, they discovered a number of surprising facts. Scattered over the country north of the Ohio and the Missouri Rivers, from New England to the mountains of the West, were stones that were different from the rock under the soil. Many different kinds of rock were found all mixed up together. Further exploration showed that the bed rock like these stones could only be found hundreds of miles to the north. The stones must, then, have come from the north.

Many of the stones were mixed with sand and clay-like material in an unsorted mass. Some of them were flattened and scratched. The bed rock in these regions was smooth and had parallel scratches that ran in a general north-and-south direction. Hard masses of rock that stuck out of the ground were rounded off and

scratched. For some time people explained these facts by saying that great floods must have covered the earth and moved these rocks long ago. But scientists began to see a more reasonable explanation. They saw that if a great glacier had come down from the north and covered the territory, the soil and the rocks would be as they are today.

We now know that glacial ice has pushed down from the north and melted back again at least four times. Much of the fertile soil of the northern part of the United States has been made by the glaciers. The Great Lakes and thousands of smaller lakes in the northern states are glacial lakes. How different our country would be if there had been no erosion and no transportation by ice!

But where do glaciers get their ice? How can a glacier flow over the land? How can geologists tell where glaciers were at work twenty-five thousand or a million years ago?

If you live where snow is common in winter, you have seen an old snow-drift that lasted far into the spring. Toward the last, the drift did not seem like snow. It was more like ice. The snowflakes had gradually changed into little granules of ice and then had frozen together into almost solid ice. That is the way glaciers form. In regions where there is much snow and where the average temperature throughout the year is cool, the snow does not all

FIG. 131. Great scratches and grooves are left in the surfaces of rocks over which glaciers have passed. Geologists call these scratches *striae*.

FIG. 132. This is Chaney Glacier, a mass of flowing ice, in Glacier National Park, Montana. Along the edges of the glacier are piles of rocks and soil. In the background you can see the U-shaped valley cut by the glacier in the bed rock.

melt during the summer. Each year more and more snow is added and changed to ice until the ice becomes very thick. In mountain regions this ice moves down through the valleys until it reaches a place where it melts as fast as it flows down.

Scientists have had great difficulty deciding how ice can move or flow. Some have thought that it can actually change its shape and flow very slowly like pitch or asphalt. However, most scientists believe that the ice melts in spots where the pressure is greatest. Then after the water has moved into a place where the pressure is lower, it freezes again. Thus the whole glacier moves along by melting and freezing again a little at a time.

The moving ice of a glacier carries with it all the loose material in its way. Stones held by the ice scrape along the bottom of the valley smoothing rough places, deepening the valley, and leaving great scratches in the solid rocks. For these reasons a glacial valley is rounded and

smooth, not rough and irregular like a valley made by a stream. The scratches on the rock show that a glacier moved over the land and also show the direction in which it moved.

At the end of a glacier, where the ice melts, its load of stones, ground-up rock, and clay is dropped. The piles of material left by a glacier are called *moraines*. Even after the ice is all gone, scientists can tell a moraine from other deposits. In a moraine the stones, sand, and clay are all mixed up together, not sorted as they are by water. Also, many of the stones have flat sides and are scratched in a peculiar way; they are not rounded and smooth as they are when they have been left by water. Sometimes the masses of material left by a glacier are called *glacial drift*.

You have noticed water streaming from under masses of snow and ice as they melt. A similar thing happens when glaciers melt, except on a much larger scale. Glacial streams may be as big as rivers; therefore, they can wear away the land and carry away much of the material brought down by the glacier. They may even wash away the moraines themselves. Sometimes when the ice melts, a moraine is left like a dam across a valley. Water collects behind the moraine and forms one kind of *glacial lake*. Other

FIG. 133. Here is a ridge of glacial drift, material that has been dropped by a glacier. Much of this will be carried away by streams running down the slope. (Ewing Galloway, N. Y.)

FIG. 134. These look like ordinary hills to you. They are really moraines that have been built up by glaciers. If you live in the part of the United States that was covered by the last glacier (see Figure 135), you have seen moraines like these many times.

glacial lakes form in low places in glacial drift and in hollows that have been dug out by the ice.

It is hard to see how a glacier could move out across hundreds or thousands of miles of almost level land and ride over the tops of high hills and low mountains. But scientists have found that Greenland is today almost covered by a glacier that moves in just that way. Near its center the Greenland ice is a mile and a half thick. The great weight in the center causes the ice to flow outward toward the edges. The ice that once covered 4,000,000 square miles of North America and a large part of Europe probably moved in the same way. The center of the glacier was far to the north in the cold Arctic regions.

Glaciers have formed and changed the surface of the earth many times in its history. The last glacier melted away from the United States about 25,000 years ago. As you know, mountain glaciers are still found in the Alps of Europe, the Himalayas of Asia, and in our own Rocky Mountains. Of course there are glaciers in the

FIG. 135. The map above shows the parts of the United States and Canada that were covered by the last great glacier. See if the glacier reached as far south as you live. If it did, your favorite lake may have been dug out by it.

North and South Polar regions. Some scientists believe that these glaciers are the remains of the glacial period of 25,000 years ago.

Self-Testing Exercises

1. How is glacier ice formed?
2. A mountain valley through which a glacier has passed looks different from a stream-cut valley near by. In what ways are they different and why?
3. What are moraines? Where are they found?
4. List the things that show where a glacier has been at work in the past.
5. Why does the ice in a glacier that is not in a mountain valley move outward from its center?

HOW ARE ROCKS FORMED FROM ERODED MATERIAL? You have often heard of limestone and sandstone. But did you ever hear of *shale* and *conglomerate?* These four different kinds of rock, limestone, sandstone, shale, and conglomerate, are formed from materials that have been eroded and transported by water, wind, and ice. Because they are found in layers, or *strata*, they are

sometimes called *stratified rocks*. And because they are formed in part from sediment in the water, they are sometimes called *sedimentary rocks*. You can discover for yourself the characteristics of the different kinds of sedimentary rock.

Experiment 20. *What Are the Characteristics of the Common Sedimentary Rocks?* For this study you will need samples of shale, limestone, and sandstone. These are the more common sedimentary rocks. Each piece of rock is called a *specimen*.

a) Study the general appearance of each kind of rock. Do glass-like crystals show in any of the specimens? If so, in which ones? Which has the finest structure, that is, has the finest grains in it? Can you see shells of animals in any of the specimens? Use a magnifier in your study if you have one.

b) Scratch each specimen with the point of a knife to test its hardness. Also try to scratch each specimen with a piece of glass.

c) Wet each specimen and smell it carefully.

d) Put a drop of hydrochloric acid on each kind of rock. Which one "boils" up most vigorously?

Limestone is usually light gray in color. It is formed at the bottoms of bodies of water, mainly from the shells and skeletons of animals. The sea animals (and sometimes plants) take dissolved calcium compounds from the water and build it into their own bodies. When the animals die, their bodies fall to the bottom of the water. The soft parts decay, but the skeletons and shells gradually build up the bottom. More and more material of the same kind settles on top, the pressure becomes greater and greater, and the whole mass of shells and skeletons is finally changed into a layer of rock.

Calcium carbonate will give off carbon-dioxide gas when it is touched with an acid. You can use this test if you do

FIG. 136. Here are strata of two kinds of sedimentary rocks—limestone and shale. The light-colored layers are limestone. The strata of shale are broken up into narrow layers.

not recognize limestone easily. However, marble, a kind of changed limestone, acts the same way.

The other three kinds of sedimentary rocks are made from the various sizes of material deposited by water or wind. Sinking of the land, about which you will learn in Problem 4, allows these deposits to be covered with water and with more material washed down by the water. Water then soaks through the materials, carrying minerals, while the material on top presses the lower layer closely together. Crystals of the dissolved minerals and the great pressure gradually fasten the pieces of gravel together to make conglomerate, the sand becomes sandstone, and the mud becomes soft shale.

The remains of plants and animals, called *fossils*, are often found in sedimentary rocks. It is easy to see how they got into these rocks. The bodies of animals that died settled to the bottom of the sea where the limestone was forming. Or they were buried in mud or sand that later became shale or sandstone. The soft parts decayed, but the hard parts remained or were changed to stone. There we find them in the rocks today. Even the tracks of prehistoric reptiles are found preserved in the rocks.

FIG. 137. This is the fossil of a fish that lived thousands of years ago. It was found in rock in a region that is now much higher than the ocean. The presence of the fossil there tells us that this area must have been at one time under water.

Under great heat and pressure far down in the earth sedimentary rocks are sometimes changed into harder kinds of rocks. Among these kinds of "changed" rocks are *marble* and *slate*. Marble is formed from limestone and sometimes shows the fossil shells from which it was made. Slate is formed from shale, which, as you know, is formed from mud.

WHAT IS THE FINAL RESULT OF EROSION? You have been learning how the surface of the earth is being constantly eroded. Can you tell what will happen to a great body of land that is continually eroded by water, wind, and ice? Rivers and waves tear down the high places and leave the material at lower levels. For the most part ice does the same thing. Only wind is able to raise material to higher levels. But it cannot raise soil to a very high place. Dunes built by the wind are never more than a few hundred feet high.

You can see, then, that a great continent with its plateaus and mountains is gradually worn down by erosion, and its materials are carried away into the oceans. Unless other changes occur, this wearing-down

process continues through millions of years until the streams flow too slowly to carry any eroded material. But other changes do occur—changes that lift up the surface of the earth. In Problems 3 and 4 you will learn how the land is raised to higher levels.

Self-Testing Exercises

1. Name three kinds of sedimentary rocks and tell briefly how each kind is formed.
2. What kind of rock is sometimes changed into marble? Into slate?

Problems to Solve

1. Tell the story of how dune sand may be changed into fertile soil.
2. How do waves help make sand dunes along an ocean or lake?
3. Has your locality been covered by glacial ice? Ask questions, read, and study the map on page 167 to answer this problem. If your region has been covered by a glacier, what evidence can you find in your locality? List the evidence.
4. How is transportation of materials by ice like transportation by water? How is it different?
5. Weathering of rock is more rapid where the weathered part is removed from the rock as fast as it becomes weathered. Explain why.
6. Which of the three kinds of erosion is now most important in the United States? Give your reasons.
7. What kinds of rock are found in your locality? Gather specimens of the solid rock that underlies the soil. You can often find the rock exposed in the beds of streams, along hillsides, or in quarries. Study the specimens and decide which kind or kinds of sedimentary rock you have found. Have your opinion checked by a teacher or by some other person who knows rocks.

Problem 3:

HOW DO VOLCANOES CHANGE THE EARTH?

For centuries people cultivated vineyards and led their cattle to pasture on the sides of a great mountain called Vesuvius, in Italy. Two ancient towns, Herculaneum and Pompeii, lay at the foot of the mountain. In the year 63 A.D. the whole region was shaken by a violent earthquake. Many of the beautiful buildings in Pompeii were destroyed, and many of the people were killed.

Fig. 138. When a volcano erupts many times, it slowly builds up a mountain that may be thousands of feet high.

In 79 A.D. more earthquakes occurred. The top of the mountain burst open, and a great cloud of poisonous gases rolled skyward and then spread over the country-side. A shower of stones and ashes from the mountain buried Pompeii and Herculaneum so deep that they were completely lost for more than 1500 years. For some years Vesuvius was quiet; then again it poured out gases, ashes, and melted rock, or *lava*. By the year 1150 there had been eight great eruptions since the eruption of the year 79 A.D.

By the year 1631 the mountain had been quiet so long that people again built their homes near it, and cattle grazed on grass that had begun to grow even in the crater. But that year another great eruption destroyed five towns and thousands of lives. Since then Vesuvius has been more or less active all the time, with

occasional great eruptions. In 1872 lava poured out of fourteen different openings in the volcano, and two villages were destroyed. Again in 1906 a spurt of activity destroyed other towns.

Such is the story of one great volcano. What causes these destructive explosions and outpourings of melted rock from down in the earth? Do all volcanoes erupt as Vesuvius has done? Why do some volcanoes seem to have ceased erupting? Geologists have studied these and other problems about volcanoes for a long time. They have learned a great deal, but they have not yet learned the real causes of volcanic activity. Let us see what geologists have discovered about volcanoes and volcanic action.

WHY IS THE INSIDE OF THE EARTH HOT? In the first place, you would probably like to know what causes the great heat that melts rocks and sends out steam and poisonous gases. However, that is one of the things the geologists have not found out. Some geologists have thought that the heat is caused by the great pressure of the earth's outer layers on the layers below. Or it may be heat that is left from the time when the earth was formed. In the last fifty years scientists have learned about radium and similar elements that give out heat energy all the time as they change into other substances. Thus it may be that the heat inside the earth is caused by these *radioactive* elements.

Even though we do not know the cause, we do know that the earth gets hotter and hotter the farther down we dig into it. In deep mines and wells the temperature rises on the average one degree Fahrenheit for each fifty feet. At this rate the temperature forty miles down would be more than 4000° F. That is much hotter than

is necessary to melt the rocks. However, the pressure of the rocks above keeps most substances from melting at their usual melting temperatures.

Scientists have other reasons for believing that most of the rock deep in the earth is not melted. They think that the rock may be *plastic*, or putty-like, so that it yields slowly to pressure, but the rock is probably not liquid.

HOW ARE IGNEOUS ROCKS FORMED? In some way masses of rock do melt deep in the earth. Perhaps they do so because some change in the earth's crust releases the pressure on them. When they have melted, the liquid rock begins to work its way toward the surface. Sometimes it never reaches the surface. Instead, it pushes its way in between layers of solid rock and begins to cool and harden. As it cools, crystals of several kinds of minerals may form. The more slowly they cool, the larger the crystals grow.

Here is an experiment that will show you how crystals grow. But instead of melting a substance to get crystals, you will dissolve the substance and then get the crystals by cooling.

EXPERIMENT 21. *How Are Crystals Formed?* (*a*) Stir some copper sulphate or some powdered alum into a small vessel of hot water until no more will dissolve. Then heat the solution to the boiling point again and keep adding alum as long as it will dissolve. Remove the vessel from the fire and use a string to hang a small nail in the center of the vessel. Then set the vessel in cold water so that it will cool quickly.

b) Repeat part *a*, but wrap the second vessel with many thicknesses of cloth or cotton and cover it so that it will cool as slowly as possible.

After several hours study the results. Did crystals form in both vessels? In which are they larger?

FIG. 139. Many of the pebbles and boulders in glaciated regions are granite. Bed rock of granite is found in Canada, in the mountains of the West, along some of the Great Lakes, and in other places in the United States.

In many places on the earth erosion has uncovered masses of rock that are made of crystals. The sedimentary rocks next to these masses show the effects of great heat. For these reasons geologists are quite sure that the crystallized rocks were melted and then hardened. Because they were formed by heat, they are called *igneous rocks*, which means "fire-formed" rocks.

Granite is one of the most common igneous rocks. Granite is very hard, and it can be polished until it is as smooth and shiny as glass. It may be different shades of red, green, or gray, according to the kinds of minerals that are in it. You can usually see three different minerals in the form of crystals in granite. One kind, called *mica*, is clear and glistens. It is soft and flaky when scratched with the point of a knife. Another is quartz that looks like dull glass and is too hard to scratch with a knife. (See page 134.) The third, called *feldspar*, is duller and less transparent than quartz or mica.

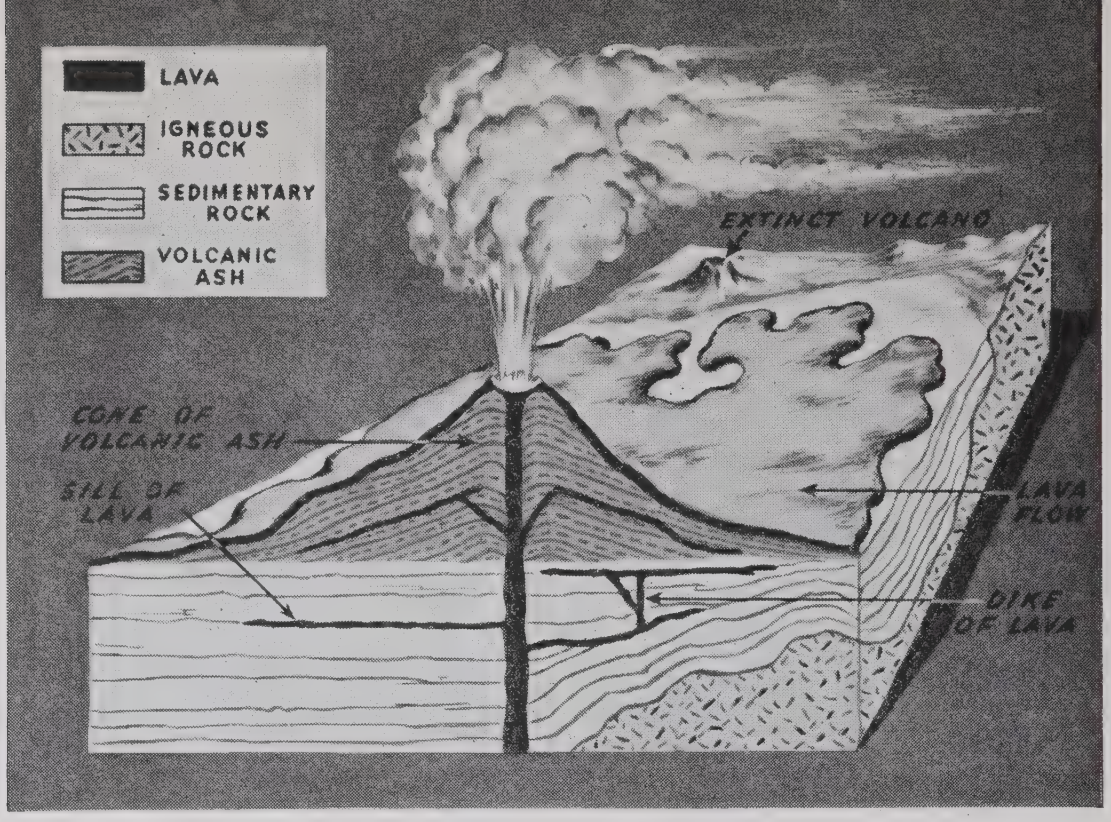


FIG. 140. This block represents a section of the earth cut through a volcano to show its structure. At the upper left you will find a key to help you locate the lava and different kinds of rocks in the drawing. A *sill* is lava that pushes in between layers of sedimentary rock and hardens. A *dike* is formed when lava pushes up, fills a crack in rock layers, and hardens.

There are several kinds of igneous rock in addition to granite. Igneous rocks are not usually found in layers, or strata, as sedimentary rocks are. Frequently you can see crystals in them. The larger the crystals are, the more slowly the rock cooled while it was forming deep in the earth.

HOW ARE VOLCANOES FORMED? When the melted rock works its way close to the top of the ground, volcanoes are formed. Often the melted rocks contain gases under great pressure. The pressure is released when the rocks above give way. The sudden expansion of the gases then causes explosions. Explosions may also be caused by steam from the water in the earth. These explosions blow the melted rock into pieces of different sizes and shoot it high into the air. Here it is cooled and hardened into *volcanic ash* and "cinders" that fall about the crater. The

FIG. 141. This is the way the dark lava that has flowed around Kilauea, a great volcano of Hawaii, looks. Many islands, including the Hawaiian Islands, have been built up by volcanic eruptions.

melted rock may continue to rise and pour out on top of the ground as lava. Cinders, ash, and lava build up the mountains we call volcanoes.

Some volcanoes remain active and erupt at intervals as Vesuvius has done. Others are closed by the cooling of the lava inside them and never again have an eruption. They are then said to be *extinct*. Many volcanoes have never been active since man has known them. The eastern United States has no active volcanoes, yet extinct volcanoes and *lava flows* are found in New Jersey and in other eastern states.

You must not think that all lava comes from volcanoes. In several parts of the world in prehistoric times great cracks opened through the rocks, and lava poured out over wide areas. One such lava flow is found along the Columbia River in Washington, Oregon, and Idaho. The sheets of lava are from 500 to 3000 feet thick and cover more than 150,000 square miles. At one place, where the river has cut through the lava, thirty different

layers can be seen. There must have been thirty different lava flows in this one region.

Do you remember how, in the story of Vesuvius, pastures and vineyards grew on the sides of the volcano within two hundred years after an eruption? This fact shows that the volcanic ash and lava weathered and changed into soil. It also shows that weathered lava makes rich soil. Much of the fertile farm and orchard land in Washington, Oregon, and Idaho has been formed from weathered lava.

Self-Testing Exercises

1. Tell briefly the story of Vesuvius.
2. (*a*) How do we know the inside of the earth is very hot? Give at least two reasons. (*b*) Give three ways in which the inside of the earth may have gotten its heat.
3. Explain briefly how masses of igneous rocks are believed to be formed in the earth.
4. How can scientists tell whether a specimen of igneous rock cooled slowly or rapidly?
5. How are volcanic ash and cinders formed?
6. Do all lava flows come from volcanoes? Explain.

Problems to Solve

1. Explain why igneous rocks do not usually show layers like those found in sedimentary rocks.
2. Why are fossils never found in igneous rocks?
3. Find some specimens of granite in your locality. Examine pebbles and boulders from the soil, paving blocks, and large buildings. If you think you have found some granite, have your opinion checked by someone who knows. Probably a shop that cuts and sells gravestones will give you chips of granite.
4. What are some famous volcanoes besides Vesuvius? Read in reference books about Mt. Etna, Krakatoa, Mauna Loa, Pelée, Shasta, and Stromboli.

FIG. 142. It takes powerful forces to push solid rock, that has a thickness ranging from hundreds to thousands of feet, into mountain ranges like these.

Problem 4:

HOW ARE MOUNTAINS FORMED?

MOUNTAINS are great barriers to travel, and it is not easy to grow crops in mountainous country. People who must live among mountains often suffer many hardships in an effort to find or raise enough food. Yet, in spite of these facts mountains have always interested and attracted people. In all parts of the world people by the thousands go to the mountains for change and recreation. Many men climb mountains for adventure. Almost every peak in the inhabited parts of the world has been climbed. But no one has ever reached the top of Mount Everest, the highest spot on the surface of the earth. That great pinnacle of the Himalaya Mountains reaches five and one-half miles into the air.

Mountains present many puzzling facts to those who think. How were they made? Have they existed ever since the earth was formed, or has some change in the earth pushed them up miles above sea level? Some mountains are rough and jagged; others are round and smooth. Why? High on the side of Mount Everest, and on other mountains in different parts of the world, are

sedimentary rocks containing fossils. These rocks must have been made in the bottom of a sea! How did they get up so high? Why are the layers of rock tilted up on edge in some mountains and bent into great folds in others? Why are some mountains made of igneous rocks instead of sedimentary rocks?

Geologists try to find the answers to these and other questions as they study the earth's crust. Although they do not yet know just how or why some things happen, they have learned many things about how mountains are made.

HOW IS THE EARTH'S SURFACE RAISED AND LOWERED? Scientists have discovered many facts to prove that the earth's land surface does not remain at the same level above the sea. The northern part of the Atlantic coast has been sinking (or the sea has been rising) during recent geological ages, that is, within the last 100,000 years. We know this because the valley of the St. Lawrence River and the valley of the Hudson River extend out into the ocean beneath the water for hundreds of miles. Great gorges are found in the rock of the ocean floor. Through these gorges the rivers once ran.

But these rivers could not possibly have dug valleys beneath the ocean. Instead, the rivers would tend to fill up the ocean near their mouths, as you learned in Problem 2. Therefore, these undersea valleys must have been at one time above the level of the ocean. Then, either the land sank or the ocean water rose. Scientists have reasons for believing that the land sank.

In the neighborhood of Lake Champlain, in New York, there is a beach now 500 feet above the lake. It is not a lake beach, either, for the shells in the sand are those of ocean animals, and the skeleton of a whale was once dug

FIG. 143. Layers of sandstone and shale, that were almost level when made, have been bent downward as if by some giant hand.

up in an inlet along the old shore-line. These facts show that much of New York was once lower than it is now, and that the ocean water once flowed over it. Sedimentary rocks also tell us that great areas of land were once under water because practically all sedimentary rocks were formed beneath bodies of water. Thus you can tell, whenever you see limestone, sandstone, or shale, that the places where you see them were once on the bottom of a sea.

The rising and falling of the earth's surface and other changes in the positions of rocks have been given a big name by geologists. These changes are called *diastrophism*. Scientists do not know the exact causes of diastrophism, but they are learning more and more about it. Many facts make them believe that there is a balance between the different parts of the earth's surface. They have found that the rocks of continents are lighter than the rocks in the deepest parts of the ocean. The continents, they

FIG. 144. Geologists find almost every possible kind of bending and folding of the layers of sedimentary rock. Notice how these layers are bent upward into an arch.

believe, were raised up by the sinking of the heavy rocks around them. This heavier rock sank deeper toward the center of the earth and pushed the lighter rock up to higher places. Thus, the heavier parts of the earth are balanced by higher masses of lighter rock in other parts of the earth.

HOW ARE ROCKS FOLDED AND BROKEN? The great unknown forces that cause diastrophism seem to act in several ways. Sometimes they raise or lower the rocks in the earth's crust. At other times they stretch the layers of rock. And more often the layers are pressed in from the sides, as shown in Figure 144. If you make a pile of long sheets of paper or strips of paper and push against the ends, what will happen? The layers of paper will bend upward in some places and downward in others. They will bend and fold over farther and farther until some of the layers are in the shape of an "S." Rocks seem to behave in much the same way.

As the rocks are bent and folded, great breaks may occur so that one part of the rock slides past another.

FIG. 145. This enormous crack in the earth was the result of an earthquake in New Zealand.

Sometimes one side is pushed over the other for miles. A break in the rocks where one side moves past the other is called a *fault*. But the rocks are not always pushed over one another at a fault. Sometimes the rock on one side moves up, and the rock on the other side moves down. Or a block between two faults may be pushed up higher than the rocks on either side.

You have probably wondered what causes earthquakes. Not a year passes without several earthquakes being reported in the newspapers. Some of the quakes are caused by volcanic activity. Others are caused by diastrophism. When a fault is made, the rocks do not seem to move slowly past each other. Instead they "stick" until the force becomes very great. Then there is a sudden jerk as the rocks slip past each other. This jerk starts the earthquake.

One of the most disastrous earthquakes in America destroyed a large part of San Francisco in 1906. A crack in the earth three hundred miles long showed where the rocks had slipped. Geologists had known that a fault was located along the line of the crack. Fences that crossed

FIG. 146. The Sawtooth Mountains in Canada were formed by the lifting and the tilting of gigantic layers of rocks.

the fault were broken, and the two ends were moved sideways from each other until they failed to meet by as much as twenty feet. Possibly every large fault has caused many earthquakes.

Now you can understand some of the changes that make mountains and mountain ranges. When a thick layer of the rock is bent upward, a range of *folded mountains* is formed. Or a fault may form, and the rocks on one side of the fault will be lifted up into a great sloping ridge. At other times the land between two faults is raised and tilted to form mountains called *block mountains*. When such changes lift a large area above its surroundings, the area is known as a *plateau*.

Mountains, as we see them today, are not formed by movements of the earth's surface alone. As soon as a part of the land begins to be lifted, erosion begins to tear it down and change its shape. Through the millions of years that the mountains are slowly rising, erosion is gnawing away at their tops and sides. The rocks that are easily destroyed are carried away. Layers and ridges of hard rock are left. Some mountains are only the hard parts of old plateaus or the ridges that have been left as streams carved out their valleys.

The mountains of the West are rough and rugged because they are comparatively young. The rocks in the

mountains of New England show all the folding and wrinkling of rugged mountains, but these mountains are much older than those of the West. Therefore they have been worn down until they are rounded and low.

Self-Testing Exercises

1. Give some reasons for believing that land rises and sinks with respect to the level of the ocean.
2. Name at least four effects of diastrophism.
3. By means of a diagram (or with modeling clay) show what a fault is.
4. Draw a diagram to show how mountains may be produced by folding and erosion of thick layers of rock.
5. Name two causes of earthquakes.

Problems to Solve

1. How can you tell an ordinary mountain peak from a volcano?
2. Tell the story of a block of limestone that is now perched high on one of our western mountains.
3. Use clay, paper, or cloth to show how rocks are folded, as described on page 182.
4. Draw a diagram to show how the heavy rocks beneath the ocean would cause light rocks to stand high in the continents.
5. Find out some of the ways in which diastrophism

FIG. 147. Lifting and erosion frequently uncover masses of igneous rocks that were formed far down in the earth. In time, all the softer sedimentary rocks are carried away, and a mass of granite or other hard igneous rock is left. Devil's Tower, Wyoming, was formed in this way.

has changed the earth in the locality where you live. You should be able to see or think of some of the effects for yourself.

6. Can you make a miniature earthquake? Find two books (or large wooden blocks) that "stick" a little when pressed together and pushed past each other. To represent a building, stand a narrow block or eraser on one of the books as it lies on or is pressed against the other. Push sideways gently on that book until it slips. What happens to your "building"?

LOOKING BACK AT UNIT 3

1. Turn to the Table of Contents and find the list of problems for Unit 3. With this list before you, write a short composition in which you answer the question, "How Does the Earth's Surface Change?" Be sure that your answer includes the answers to all four problems of the unit.

2. Make a list of the things you have learned in this unit that you think are most interesting and valuable to you.

3. Show that you know the meaning of the following words:

block mountain	*plateau*	*loam*	*stalagmite*
flood plain	*moraine*	*quartz*	*diastrophism*
ground water	*erosion*	*delta*	*sediment*
igneous rock	*fault*	*humus*	*weathering*

ADDITIONAL EXERCISES

1. Make a list of all the different ways in which rock is used in your locality.

2. How are icebergs formed from glacier ice?

3. How does erosion produce waterfalls? (Geology and physical-geography books will help you answer this and several of the following questions.)

4. What are ox-bow lakes, and how are they formed?

5. There are several different kinds of moraines. What are the different kinds, and how do they differ from one another?

6. How much salt is there in a gallon of ocean water?

FIG. 148. The Grand Canyon in Arizona tells geologists a fairly complete story of the earth. The Colorado River has cut the deep canyon revealing the wall of rock layers. Each layer was made under water. When something happened inside the earth, great mountains were made. Then water began to wear down the rock again.

7. Does salt in water make mud settle more quickly? Plan an experiment that will answer this question.

8. The bottoms of some of the Great Lakes are below the level of the ocean. How could they have been eroded so deeply?

9. Learn to read *contour maps*. This kind of map is used a great deal by geologists. You can find some contour maps in geology books and physical-geography books, together with explanations of their meaning.

10. Write to the United States Geological Survey, Department of the Interior, Washington, D. C., to find if a contour map of your locality has been made. If so, obtain one and see what you can learn from it.

11. Write to the State Department of Geology, at your state capital, for information about the geology of the place where you live.

12. Collect articles from newspapers and news magazines about such happenings as earthquakes, floods, and volcanic eruptions. Make them into a carefully organized clipping

book. Include maps on which you mark the place where each happening occurred.

13. Prepare a "Book of Scenic Wonders" in which you collect information about such places as Grand Canyon, Mammoth Cave, and Yellowstone National Park and their geological history.

14. Find out where the petrified forest is located and how it was formed.

15. Do you think that rocks are being formed today? Where?

16. In some regions when a farmer digs up a rock that is rounded and rather soft on the outside, he says that the rock is growing. Do you think that opinion correct? Why?

Fig. 149. In 1783 Jacques Charles, a French scientist, built a balloon that had most of the features of a modern balloon. It was made of varnished silk and was filled with hydrogen. It took four days to make enough hydrogen to fill it. Thousands of people gathered in Paris to watch the balloon rise with two men in it. In this unit you will find out what makes things rise in air and in water.

UNIT FOUR

UNIT 4

WHY DO SOME THINGS RISE AND OTHERS SINK IN FLUIDS?

INTRODUCTORY EXERCISES

1. Make a list of materials that float in water and another list of materials that do not float in water. Try to think of a statement that will explain why some materials float, while other materials sink.

2. Steel does not float in water, yet boats can be made of steel. Explain.

3. When an object is lowered into water, does its weight seem to become more or less or to remain the same? How do you know?

4. How is a submarine made to submerge and to rise to the surface at the will of the pilot?

5. A large balloon filled with hydrogen can carry thousands of pounds of passengers and cargo. Is this load lifted by the hydrogen or pushed up by the air? Explain briefly.

6. Which way does the air around a warm stove move? Why does it move in that way?

*7. (*a*) What is the meaning of the word *expand?* Of *contract?* (*b*) Do substances expand or contract when they get warmer? How do you know?

8. Does the density of a substance become greater or less or remain the same when it contracts? Why do you think so?

9. Imagine that you are heating some water in a dish pan with a Bunsen burner. Draw a diagram to show how the water would move while it is being heated. Explain briefly why it would move as you have shown.

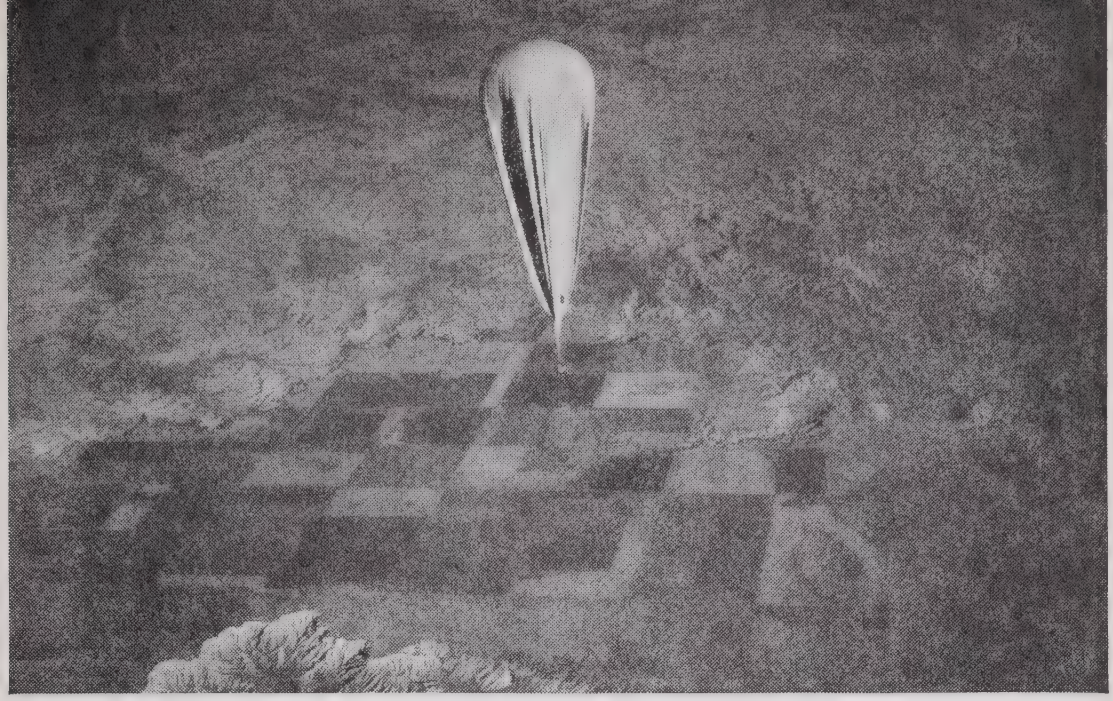


FIG. 150. When the balloon of Captains Stevens and Anderson reached the height of 72,395 feet above sea level, it was 43,254 feet higher than Mt. Everest, the highest mountain. Scientific instruments were carried for learning about the *stratosphere*, or thin air above the earth. How could more than four tons of balloon and load be lifted to that great height?

LOOKING AHEAD TO UNIT 4

BABY JANE was having her bath. In the tub was a big cake of white soap. Jane held the soap tightly with both hands, but it slipped out of her wet fingers and fell with a splash into the water. She reached for it and pushed it clear to the bottom of the tub before it slipped away from her again. This time, though, the soap bobbed *up* right under her nose. Of course, you know that gravity made the cake of soap fall into the water. But what force made the soap come up to the top of the water?

At dawn on November 11, 1935, the largest balloon ever made rose slowly into the air from a great hollow in the ground near Rapid City, South Dakota. In the metal sphere that hung below the balloon were two army flyers, Captain Anderson and Captain Stevens. Just as the balloon passed over the edge of the hollow, it started downward. Anderson and Stevens desperately dumped out bag after bag of lead dust to lighten the load. Finally

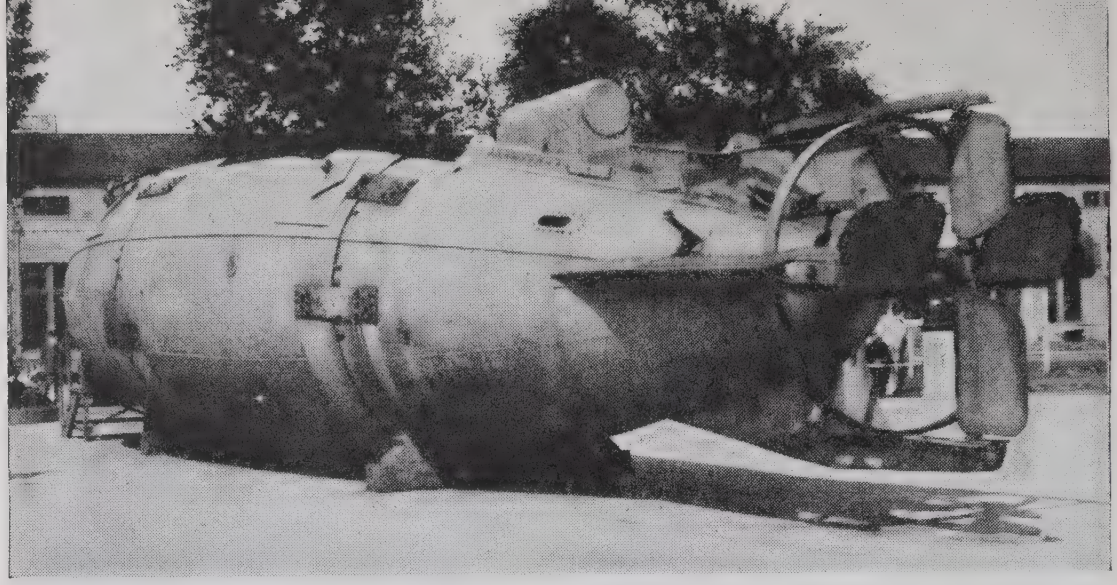


FIG. 151. In 1877 John Holland, an Irish-American inventor, built the first submarine. It was about fifty feet long and looked like a cigar of steel plates. Compare it with the modern submarine shown in Figure 159, page 202. (Ewing Galloway, N. Y.)

the balloon started upward again. It went up and up, until at noon the two men were looking at the earth and sky from the greatest height ever reached by man—13.71 miles above sea-level. What force could hold them so high in the air?

At Christmas time Uncle Dave gave Bob and Mary a half dollar to buy new ornaments for their tree. Some of the ornaments they bought were little shades for the lights on the tree. But these were no ordinary shades! Each one had a little windmill arrangement at the top. When the lights were turned on, the camels of the Wise Men and Santa Claus's reindeers traveled round and round. What force made the shades turn? Why did they stop when the lights were turned off?

The force that was acting in each of these incidents was the same—gravity. In Unit 2 you learned much about gravity, but it seemed always to pull things down. How can it lift a cake of soap in water, a great balloon into the sky, or make a little Christmas-tree ornament go round and round? Read this unit thoughtfully and do the experiments carefully. Then you will see how gravity, pulling downward, can make things go *up*.

Problem 1:

WHY DO SOME OBJECTS FLOAT AND OTHERS SINK?

A SUBMARINE is a strange boat. Sometimes it travels along the top of the water like any other boat. At other times all openings are closed, and it sinks beneath the surface. It may not come up again for many miles, yet when the captain gives the word, it rises to the surface again. The submarine can do these things because the men who made it and the men who run it understand one of the laws of science called *Archimedes' Principle.* You can understand it, too, if you will study Problem 1 with care.

WHY IS AN OBJECT EASIER TO LIFT WHEN IT IS IN WATER? More than two thousand years ago a very wise man, named Archimedes, was given a problem by his king. Archimedes was to tell the king whether his new crown was made of pure gold, but he was not to injure the crown in any way. Archimedes decided that the best way would be to find the density, or weight per cubic inch, of the crown. Gold has a greater density than any other metal that was known in those days. If silver had been mixed with the gold of the crown, the density would have been less than that of gold.

To find the density of the crown, Archimedes needed only to find the weight of the crown and the number of cubic inches of metal in it. To find the weight of the crown was easy. But the crown had such an irregular shape that he could not think of any way to measure the number of cubic inches in it. While taking a bath one day, he noticed that the water rose in the bathtub when he got into it. His great mind quickly saw that he had found the answer to his problem and that he had discovered another great law of nature. What Archimedes

FIG. 152. Apparatus for Experiment 22

discovered you can discover by doing the next two experiments.

EXPERIMENT 22. *How Does the Weight of a Stone in Air Compare with Its Weight in Water?* (*a*) Tie a thread or string about a stone of convenient size. Hang the stone on a spring balance marked in grams. Find the weight of the stone in air.

b) Then lower the stone into a jar or pan of water so that it is entirely covered but does not touch the jar (Figure 152). Does it weigh the same as it did in air? What does its weight seem to be? How many grams did the stone seem to lose?

EXPERIMENT 23. *How Does the Weight Lost by a Stone in Water Compare with the Weight of the Water It Displaces?* (*a*) Fill a large graduated cylinder (Figure 153) half full of water and notice carefully the number of cubic centimeters of water you have. (Be sure to use the mark that is even with the level part of the water, not the one at the curved-up edge.) Lower the stone used in Experiment 22 into the water in the cylinder. Read the number of cubic centimeters of space filled by both the water and the stone. Find out how many cubic centimeters of space the stone fills.

b) One cubic centimeter of water weighs one gram. How many grams of water were pushed aside or displaced by the stone? How many grams of weight did the stone lose when it was in the water? How do the two figures compare?

c) Repeat Experiments 22 and 23 with two or three other stones or convenient objects that will neither float nor absorb moisture. What is your answer to the problem of this experiment?

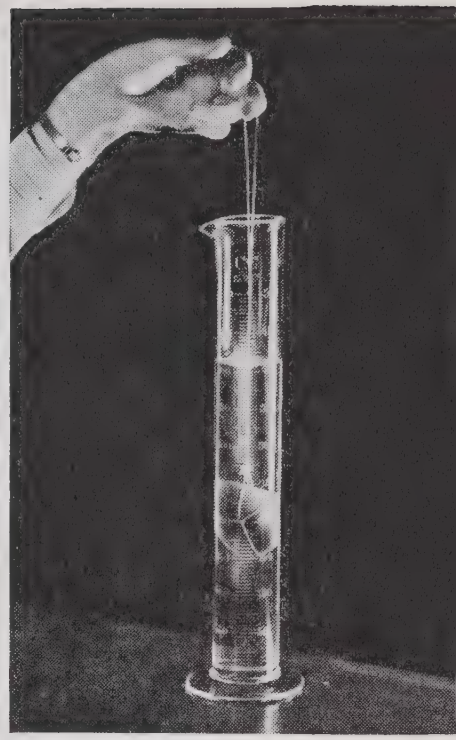


FIG. 153. Experiment 23

Perhaps you have never tried to lift a large stone out of a pond of water and noticed how its weight seemed to change when it came up into the air. The first of your experiments shows that a stone really does seem lighter in water than in air. Can you tell why this is true?

If your measurements in Experiments 22 and 23 were carefully made, you probably found that the weight lost by your stone was, as nearly as you could tell, equal to the weight of the water it pushed aside when you lowered it into the cylinder.

Do you see, now, what Archimedes found out? He saw that the water lifted his body with a force that was just equal to the weight of the water which had filled the space where his body was. In other words, if his body pushed aside two cubic feet of water, then his body was being lifted by a force of 124.8 pounds. (Water weighs 62.4 pounds per cubic foot.) His body weighed 124.8 pounds less in the water.

When Archimedes saw this, it was easy for him both to weigh the crown and to find how much metal there was in it. All he had to do was to weigh the crown on a

pair of balances, then lower it into water and weigh it again. The loss in weight would tell him the number of cubic inches of metal in the crown.

It is said that Archimedes was so excited when he saw how to solve his problem that he ran all the way home, shouting "Eureka" (I have found it) as he went. The principle that he discovered has ever since been called by his name. Archimedes' Principle is stated in this way: *Any object placed in a fluid is buoyed up (pushed upward) by a force equal to the weight of the fluid that it displaces.* (A *fluid* is a substance that will flow. Water and air are both fluids.)

Exact experiments show that Archimedes' Principle is true. But why is it true? How can water lift up a stone that is placed in it?

To understand the answer to this problem, you will need to recall what you know about pressure in liquids. In the first place, we know that any liquid pushes in all directions (page 89). That is, when the stone was under water, the water was pushing up on the bottom, down on the top, and against the sides. In the second place, the deeper anything goes into a liquid, the greater the pressure becomes. (See page 92.) The bottom of the stone was farther down in the liquid than the top. Thus the water pressed up harder on the bottom than it pushed down on the top. The extra force on the bottom tended to push the stone up and make it easier to lift. Careful measurements show that the extra force that tends to overcome the gravity of the stone is just equal to the weight of the water that would go in the space the stone occupies.

To see clearly what this principle means, imagine that you have a block of stone which contains exactly one

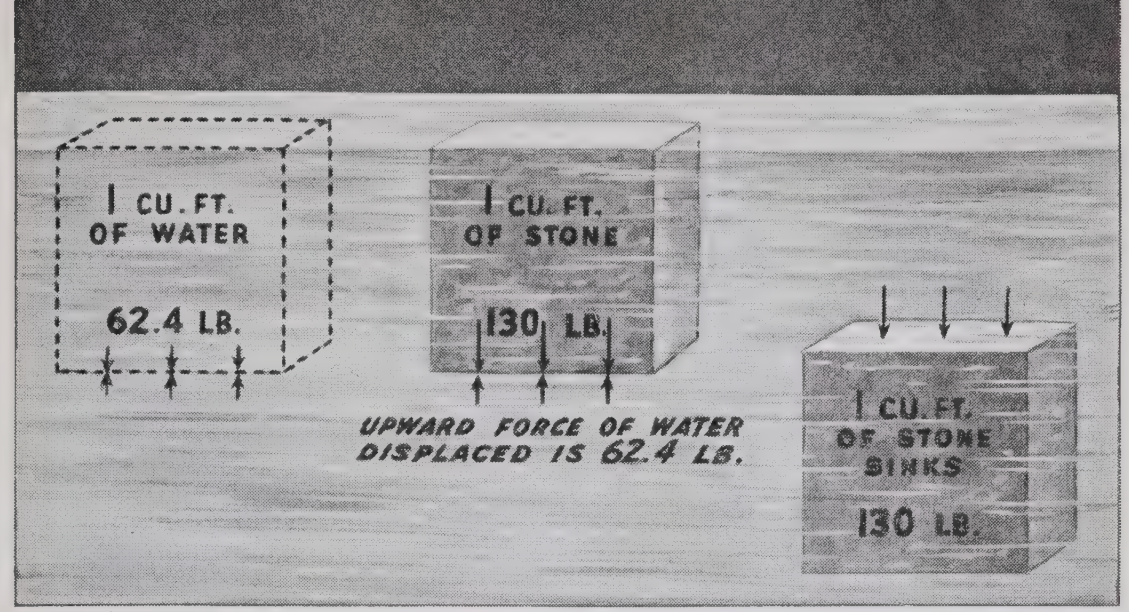


FIG. 154. If a cubic foot of stone weighing 130 pounds is held under the surface of the water, the upward force of the water will be less than the downward pull of gravity. When the block is released, it will sink in the water.

cubic foot. The cubic foot of stone weighs 130 pounds. Water weighs 62.4 pounds per cubic foot. Now you lower the stone into water. The stone pushes aside one cubic foot of water. It seems to get 62.4 pounds lighter. Your stone would seem to weigh only 67.6 pounds (130 pounds minus 62.4 pounds).

Gravity is pulling down with a force of 130 pounds on the stone. But at the same time gravity is making the water push up on the bottom of the stone 62.4 pounds harder than it is pushing on the top of the stone. The pull of gravity on the stone wins, and the stone sinks in the water. In the same way any object will sink in a liquid if it weighs more than the liquid it displaces.

Self-Testing Exercises

1. Tell why Baby Jane's soap came to the top of the water, as described on page 191.

2. There are two cubic feet of iron in a certain bar. How much weight would the bar seem to lose in water?

3. What is Archimedes' Principle? Give an example of the way this principle works.

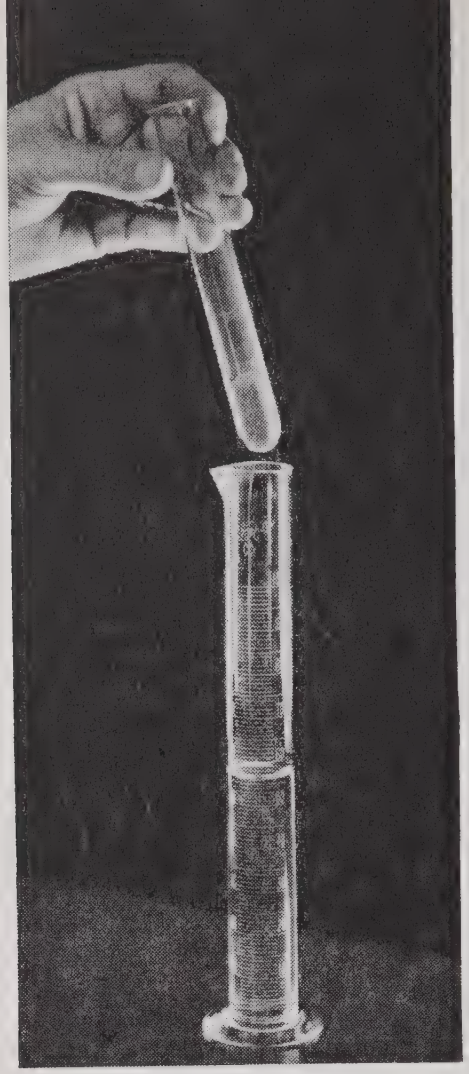


FIG. 155. Apparatus for experiment 25

Problems to Solve

1. Many people think that when a ship sinks, it goes only part way to the bottom of the ocean. Is this true or not? How do you know?

2. Some boys were clearing out the bottom of a stream to make a swimming pool. They discovered a large stone in the bottom. They could lift it to the surface of the water, but they could not lift it out of the water. Explain.

WHY DO SOME OBJECTS FLOAT IN LIQUIDS? Of course, you know that some things float. This also is caused by a "contest" between the weight of the liquid and the weight of the object. Let us see how this contest works.

EXPERIMENT 24. *How Can a Piece of Dense Metal Be Made to Float in Water?* (*a*) Obtain two pieces of tin-foil, each about three inches square. Roll one piece into a ball and drop it into a pan of water. Does it sink or float? Why?

b) Fold the second piece of tin-foil into a shallow box-like shape. You can do this easily by pressing it around the end of a block two inches square. Remove it from the block and place it bottom downward on the water in the pan. Does it float or sink? Why?

EXPERIMENT 25. *How Does the Weight of a Floating Object Compare with the Weight of the Water It Displaces?* (*a*) Put just enough sand in a test-tube to make it float upright in water. Dry the tube carefully and find the weight of the tube and the sand in grams. Fill a 100-cubic-centimeter graduated cylinder about half full of water and record the exact number

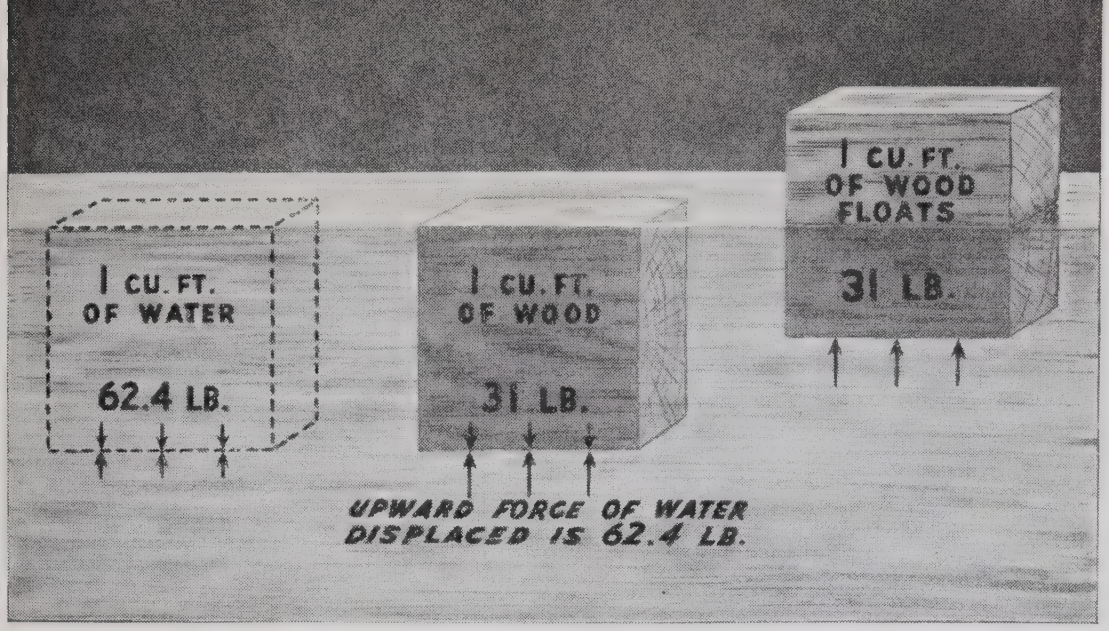


FIG. 156. If a cubic foot of wood weighing 31 pounds is held under the surface of the water, the upward force of the water will be greater than the downward pull of gravity. When the block is released, it will rise to the point where the upward and downward pressure are equal.

of cubic centimeters of water it contains. Lower the weighted tube carefully into the water in the graduated cylinder and notice what happens to the water.

How many cubic centimeters does the water rise? Compare the weight of this number of cubic centimeters of water with the weight of the tube and the sand before they were placed in the water.

b) If you wish to do so, drop a five-gram weight into the test-tube and measure the rise of the water in the tube. Continue to add weights and measure the displacement until the water reaches almost to the top of the test-tube.

Blocks of wood, tin cans, stoppered glass bottles, and steel ships all float in water. Some may even float with the larger part of them above the surface of the water. Can you explain why they all float, even though pieces of steel, glass, and tin will sink?

Let us begin with the block of wood. A cubic foot of pine wood weighs only about one-half as much as a cubic foot of water; that is, it weighs about 31 pounds. When a cubic foot of wood is placed under water, there is a push of water on the bottom of the block. This

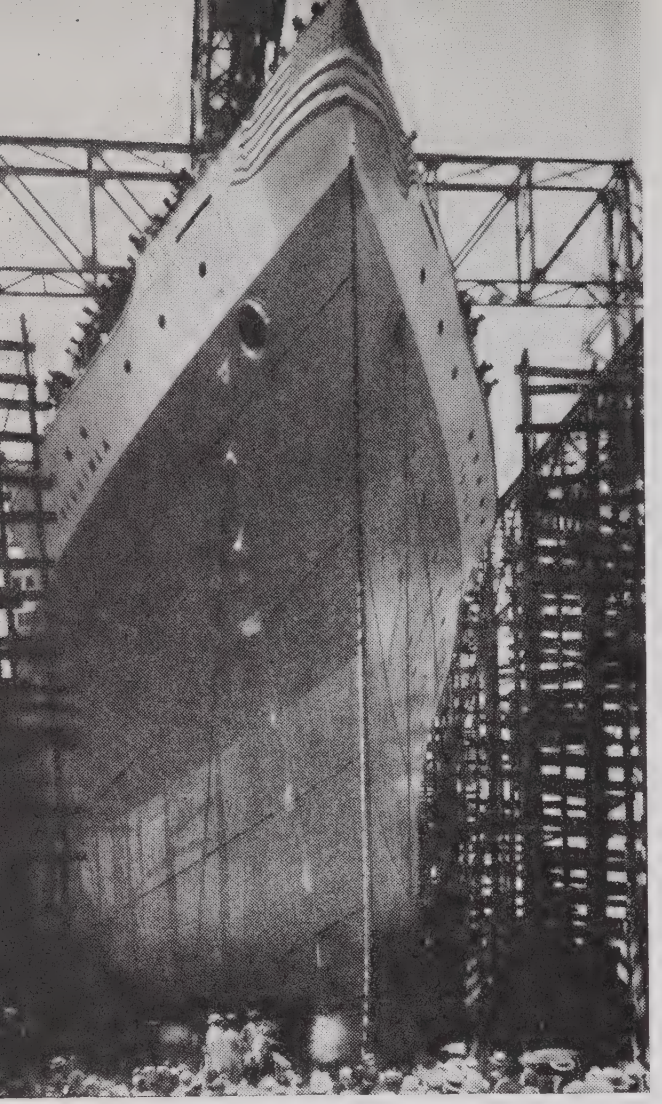


FIG. 157. The white numbers on the bow of this liner tell how many feet of water it displaces. The amount of water displaced varies with the cargo.

push that lifts the block against gravity is 62.4 pounds. Gravity pulls down on the block with a force of about 31 pounds. The water wins the "push of war," and the block must go upward until it stands above the surface of the water and displaces only about one-half a cubic foot of water, because one-half a cubic foot of water weighs about 31 pounds. In the same way any material that weighs less per cubic foot than a liquid will float in the liquid.

But what about iron and glass? They are denser than water, yet they can be made to float. You probably know that the cans, bottles, and steel ships that float are all "hollow." When they are placed in the water, they push aside a much larger weight of water than the material in them weighs. Archimedes' Principle is true here also.

When a hollow steel ship is launched, it sinks until it displaces enough water to equal its own weight. Then it stops sinking because the force of the water on the bottom is equal to the pull of gravity on the ship. If it should sink deeper, the force pushing up on the bottom would become greater, and the ship would be pushed upward until the two forces were equal. When the ship is loaded at the wharf, it sinks into the water until the additional water displaced just equals the weight of the cargo.

When you read about the great ships of different countries, you are told about their *displacement*. What does displacement mean? And why is the displacement of a great ship like the *Queen Mary* important? When a ship floats, it pushes aside, or displaces, just as many tons of water as it weighs. Thus the displacement of a ship is really the same as its weight.

Have you ever seen the little floating instrument, called a *hydrometer*, that is used to test the storage batteries in automobiles? As a battery is charged with electricity, the density of the sulphuric-acid solution in it increases. As the battery "runs down," the solution becomes less dense. The hydrometer is a glass tube with a weight in one end so that it will float upright in a liquid. (The weighted test-tube you used in Experiment 25 could be used for the same purposes as a hydrometer.)

FIG. 158. Hydrometers are used for measuring the density of anti-freeze and alcohol solutions in auto radiators and for many other practical purposes.

When the sulphuric-acid solution is dense, the tube sinks far enough to displace its own weight in the solution. When the solution becomes less dense, the hydrometer must sink farther to displace enough liquid to equal its own weight. Numbers on the scale tell the density. From these numbers the persons using the hydrometer can tell whether the storage battery needs to have more electricity sent through it.

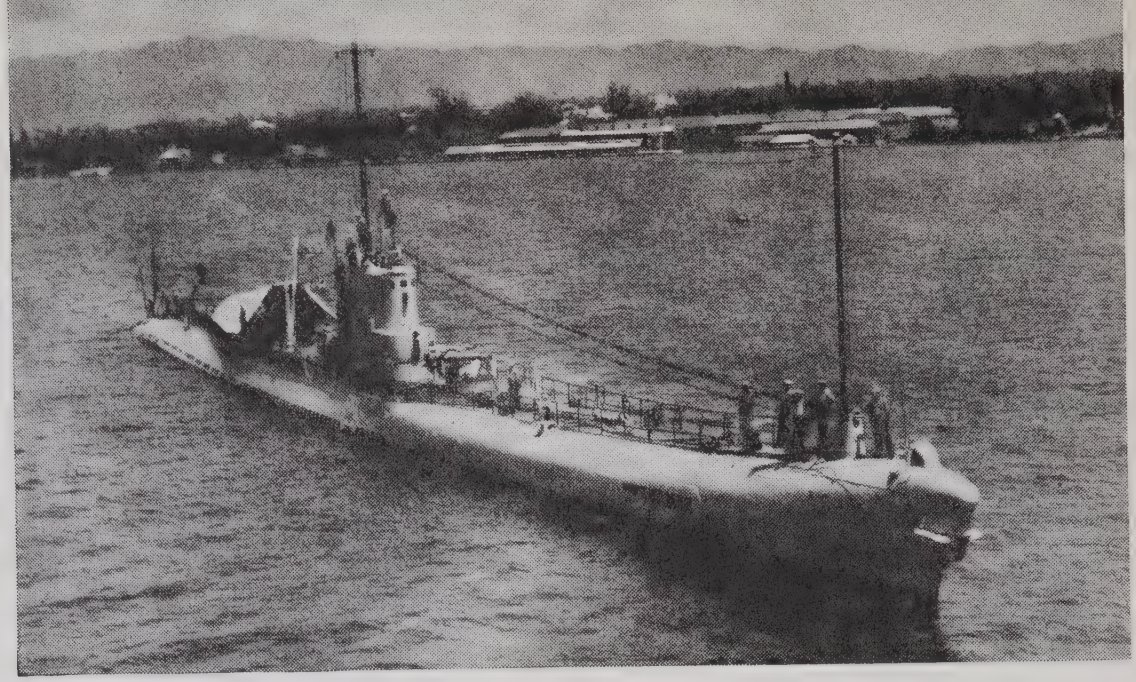


FIG. 159. The modern submarine may be over 350 feet long and have a displacement of over 3000 tons. It can travel at a speed of thirty to thirty-six nautical miles (6080 feet per mile) an hour on the surface and fifteen miles an hour below the surface.

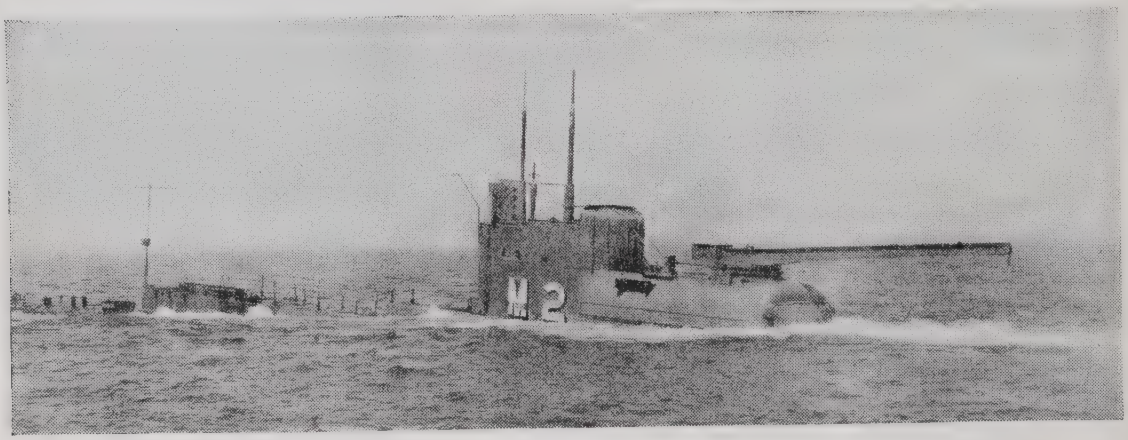


FIG. 160. This submarine has let some of the sea water into its diving tanks and has begun to sink below the surface of the water. This submarine is unusual in that it carries an airplane in a water-tight hanger on top.

You can now understand that any body that sinks in a liquid weighs more per cubic foot than the liquid. Any body that floats weighs less per cubic foot. By measuring how far a floating body like a battery-tester sinks in a liquid, we can measure the density of the liquid.

Now let us return to the problem of the submarine. Why does it sometimes float on the water and sometimes sink below the surface? You know that when the sub-

marine is floating on the water, it must be less dense than water. It is less dense because of its hollow steel body. However, the boat is made with several "diving tanks" in it. These are compartments into which the water may be allowed to run and from which it can be pumped out. When the command to dive is given, water is allowed to enter the diving tanks until the boat becomes just about the same weight as the water it displaces when it sinks below the surface. The submarine can then move through the water at any depth down to about two hundred feet.

Special diving rudders are used to guide the boat upward or downward as it moves through the water. When the captain wishes to have the boat come to the surface, air is pumped into the diving tanks. This air pushes the water out, the submarine becomes lighter, and the water pushing against its lower side sends it to the surface.

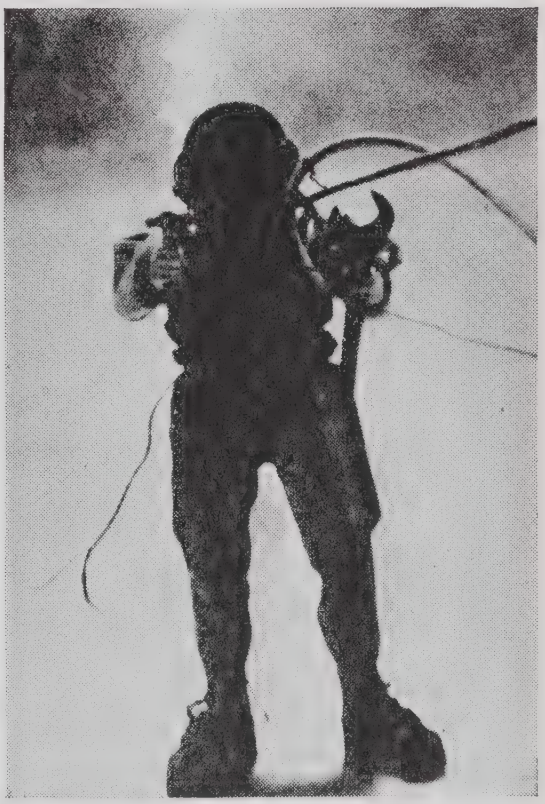


FIG. 161. This diver was photographed while repairing broken pipes in a swimming pool. Notice the heavy lead soles on his shoes. (Ewing Galloway, N. Y.)

The men who work under water in diving helmets and waterproof diving suits must use a knowledge of Archimedes' Principle. A man's body is just a little denser than water. With the lungs full of air, almost anyone will float. With the lungs empty of air, or full

of water, almost anyone will sink. When a diver starts down into the water, his suit is filled with air. Even though the helmet is heavy, he will barely sink, or he may even float. To carry him down and help him walk firmly on the bottom, the diver must have shoes with heavy lead soles and, in addition, lead weights fastened about his body.

Self-Testing Exercises

1. When an object floats on water, what do you know about its density?
2. Steel sinks in water, but steel ships float. Tell why.
3. Many life-boats on ocean ships have air-tight hollow spaces in their sides. How does this kind of structure make the life-boats safer?
4. What does a hydrometer tell about a liquid, and how does it tell it?

FIG. 162. An iceberg may be 250 to 300 feet above the surface of the water. But this is only about one-eighth to one-tenth of the whole iceberg. For this reason icebergs are a deadly peril to ships in the North Atlantic. The U. S. Coast Guard cutter is on duty to guide and to aid ships. (Ewing Galloway, N. Y.)

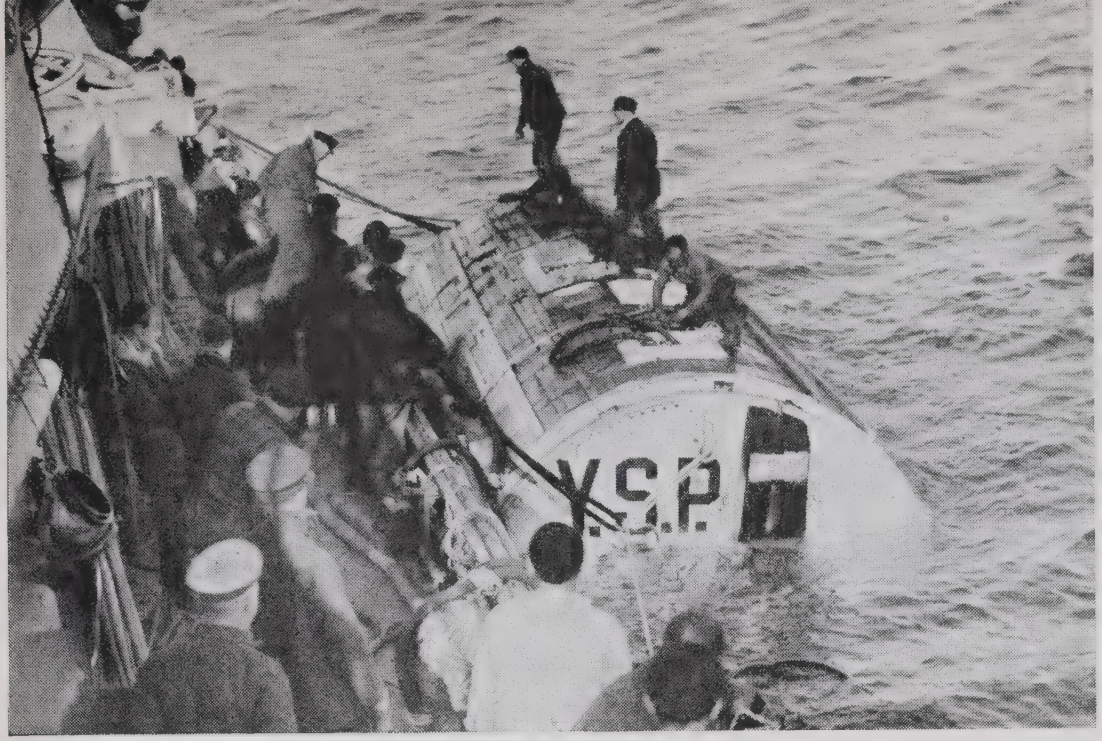


FIG. 163. A certain wrecked submarine was to be raised. Divers sank large tanks that were full of water and chained them to the wreck. Then the water was forced out of the tanks, and the sunken submarine came to the surface. Explain why this plan worked.

Problems to Solve

1. Mercury weighs 849 pounds per cubic foot; gold, 1194 pounds; iron, 487 pounds; platinum, 1204 pounds; and silver, 655 pounds. Which metals would float in mercury, and which would sink?

2. Does ice float or sink in water? What does this tell you about the density of ice as compared with that of water?

3. (*a*) Explain how a submarine uses Archimedes' Principle. (*b*) What is done to bring a submarine to the top of the water? Why does this plan work?

4. (*a*) If a ton of goods is loaded on a ship, how much water will be pushed aside by the settling of the ship? (*b*) How many cubic feet of water will be pushed aside? (A cubic foot of water weighs 62.4 pounds.)

5. A stone weighs 135 pounds in air but 73 pounds in water. How many pounds of water does the stone displace? How many cubic feet?

6. If your body just floats in fresh water, about what is its average density? The volume of your body is how many cubic feet?

7. How could you use the test-tube weighted with sand for Experiment 25 to tell whether a liquid is more or less dense than water?

8. Make a toy "submarine" for yourself. Get a large bottle or jar and a small bottle or test-tube that will go inside the first one. Fill the large bottle or jar with water. Put some water in the small bottle and turn it upside down in the large bottle. To be successful, the small bottle must just float in the large one. You may need to make several trials to get it just right.

Now see that the large bottle is completely full of water. Then cover its mouth tightly with a piece of thin rubber (a piece of toy balloon or old rubber glove), and fasten it there with string or rubber bands wound tightly around the bottle. To make the little "submarine" dive, you need only press gently on the rubber cover of the bottle. By pressing with more or less force, you should be able to make the little bottle obey your commands. Explain why it goes up and down as it does.

WHY DO BALLOONS RISE IN THE AIR? Have you ever seen a great passenger balloon floating in the air? The huge cigar-shaped balloons, called dirigibles, are built about a framework of aluminum alloy. Within the framework are large silk and rubber bags that are filled with a gas. Inside the balloon are also fuel tanks, rooms for the crew and passengers, and passageways from one part to another. Suspended on the outside are several motors with propellers to drive the balloon through the air.

The great airship *Hindenburg*, which made many trips across the Atlantic Ocean before it burned in 1937, was more than 800 feet long. With crew and equipment it weighed 430,000 pounds, and it carried a load of 42,000 pounds. Yet this great mass of material floated in the air almost as easily as the toy balloons you buy at the circus. How was this possible?

In Unit 2 you learned that air has weight. Any object

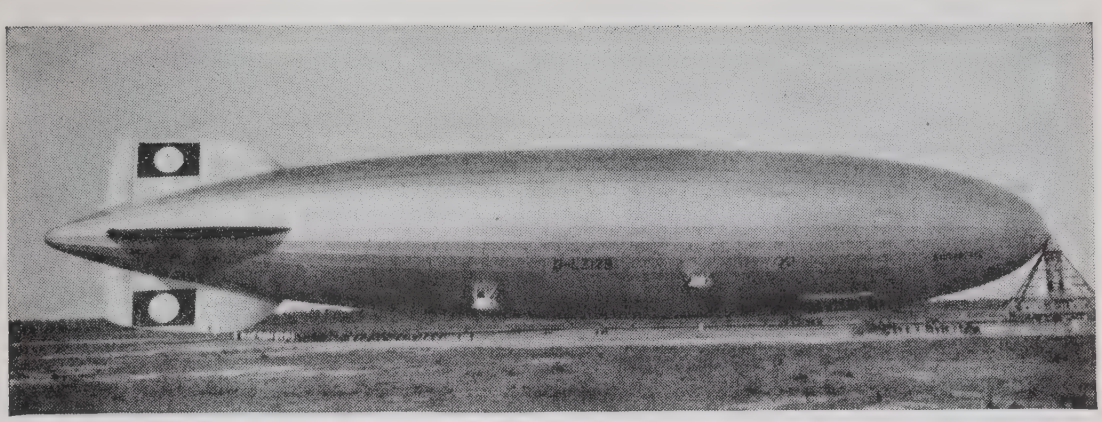


FIG. 164. This is a dirigible, more than 800 feet long, tied to its mooring mast. The white spots on the side are two of its powerful motors. A dirigible differs from an ordinary balloon in that its flight can be directed by means of its motors, propellers, and rudders.

in the air must behave according to Archimedes' Principle. That is, it will be pushed upward by a force equal to the weight of the air that it displaces. This is true because the air pressure on the bottom of the object is greater than that on the top (page 104).

We do not notice this lifting force on a dense object such as a brick. But when a balloon is filled with a gas that is less dense than air, the air around the balloon pushes upward on the balloon harder than the balloon with the gas inside it is pulled downward by gravity. Thus the extra upward force of the air on the bottom lifts the balloon.

Toy balloons that rise in the air are usually filled with hydrogen. Many large balloons also are filled with hydrogen. One thousand cubic feet of hydrogen weigh about 5.6 pounds, but 1000 cubic feet of air at the surface of the earth weigh about 87.9 pounds. From these facts you can see that 1000 cubic feet of hydrogen in a balloon on the ground will be pushed upward by the air around it with a force of 82.3 pounds (87.9 lb. − 5.6 lb.). Thus, with a balloon holding 1000 cubic feet of hydrogen, the

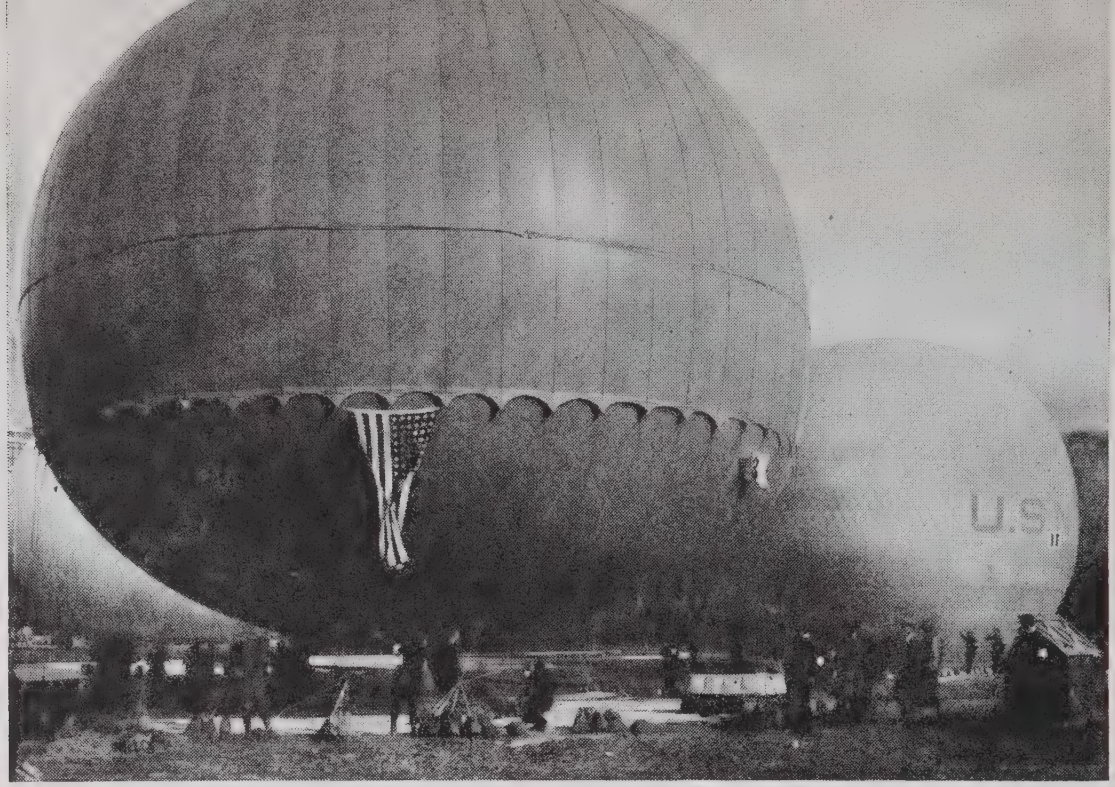


FIG. 165. International balloon races are held each year in different countries. These American balloons are getting ready to take part in a race at Brussels, Belgium. The balloons are held down by sand bags while being filled with hydrogen. (Ewing Galloway, N. Y.)

air will lift 70 pounds of rubber and cloth and also a load of twelve pounds.

The gas-bags of the *Hindenburg* displaced more than 7,000,000 cubic feet of air. This much air weighs about 507,200 pounds. The hydrogen that filled the balloon weighed about 35,200 pounds. The air on the outside of the gas-bags thus pushed up on them with a force that was 472,000 pounds more than the weight of the gas inside. Since the great balloon itself with all its equipment and with its crew weighed about 430,000 pounds, the balloon could still carry a load of 42,000 pounds in passengers and goods.

However, a balloon full of hydrogen is a rather dangerous companion on a journey. Any spark is likely to set some leaking hydrogen on fire. (A spark and leaking hydrogen got together in the case of the huge *Hindenburg*.) Fortunately there is another gas, *helium*, that does not burn and therefore can be used with greater safety.

Helium is now used in some of the large balloons. This gas is denser than hydrogen (1000 cubic feet weigh about 11.2 pounds) and more expensive, yet the advantage of safety with helium is often greater than its disadvantages of added density and cost.

A balloon floating in air is different in one very important way from a boat floating in water. It does not go all the way to the top of the air. Why is this true? To understand the answer to this question, you must remember that the air near the earth has a greater density than the air high above the earth (page 105). That is, the weight of the air per cubic foot gets less and less as we go higher and higher. The upward push of the air on a balloon depends on the weight of the air it displaces.

As it goes up, a balloon may displace 1000 cubic feet of air all the time. However, at the height of a mile, 1000 cubic feet of air weigh much less than the same amount of air weighs at the surface of the earth. When a rising balloon gets to the height where the weight of the air it displaces is equal to the weight of the balloon (including the gas in the balloon), it stops rising.

The men who go up in large balloons, like the stratosphere balloons, have two ways to control the rising and sinking of their balloons. These two ways are: (1) throwing out something to make the balloon lighter; (2) letting some of the gas escape from the bag so that it will not be pushed up so hard by the air. The stratosphere flyers carried a large amount of powdered lead for *ballast.* Some balloonists carry bags of sand for the same purpose. When they want to rise higher, or when they want to stop sinking, they pour out some of the ballast. If they wish to stop rising or to descend, they let some gas out of the balloon.

FIG. 166. When the pilot of this balloon wants to go higher, he will drop some of the sand bags. (Ewing Galloway, N. Y.)

Self-Testing Exercises

1. (*a*) Is the pressure of the atmosphere greater against the bottom or the top of a balloon? (*b*) What causes the difference? (*c*) Why is this difference important to passengers in a balloon?

2. Why are toy balloons filled with hydrogen?

3. Explain why the dirigible balloon, the *Hindenburg*, in addition to its own weight, was able to lift a load of about twenty-one tons against the force of gravity.

4. If soap bubbles are blown with the gas burned in laboratory burners and in stoves (illuminating gas), these bubbles will float up toward the ceiling. What does this tell you about the density of illuminating gas?

5. What determines how far up a balloon will go? How does the balloonist control the rising and sinking of the balloon?

Problems to Solve

1. A pound of sugar was very carefully weighed in a laboratory. Then it was placed inside a glass jar on a very sensitive balance. The air was pumped out of the jar. Did the sugar seem to gain weight, lose weight, or remain the same while the air was being pumped out of the jar? Give reasons for your answer.

2. (*a*) A can filled with hydrogen was weighed in the air and again in a vacuum. Where did it seem to weigh more? Why? (*b*) Did the balance in the vacuum show the true weight of the can and the hydrogen? How do you know? (*c*) After the hydrogen was let out of the can, the can alone was weighed in a vacuum. Did it weigh more than, less than, or the same as it did when filled with hydrogen and in the vacuum?

3. In a certain experiment soap bubbles filled with air were allowed to settle into a jar that was apparently empty. The bubbles went only part way down in the jar and floated there for some time. What does this tell you about the gas in the jar?

4. A balloon holds 12,000 cubic feet of hydrogen gas. The balloon with all its equipment weighs 900 pounds. How many pounds of crew, passengers, and ballast can it support?

Problem 2:

HOW DOES GRAVITY CAUSE WATER AND AIR TO CIRCULATE?

How do fluids move when there are differences of temperature? You have probably noticed that the air around a radiator or stove is always moving upward. The smoke of a fire almost always goes upward. But have you noticed that both water and air begin to move almost every time there is a slight difference of temperature between two places in these fluids? Let us watch the circulation in a few such places.

Experiment 26. *How Does Warm Water Behave in Cold Water?* Obtain a wide-mouthed bottle that will hold about one-half pint. Have a stopper to fit. A wooden plug will do. Fit tubes in two holes in the stopper, as shown in Figure 167. Have these tubes as large as convenient. Put a few drops of ink in the bottle, fill it to the top with hot water, and put the stopper in tightly. Gently lower the bottle into a jar or bucket filled with cold water. Be sure the water in the large vessel reaches

Fig. 167. Experiment 26

above the top of the outer tube. Where does the warm water go? What goes into the bottom of the bottle?

EXPERIMENT 27. *How Does Cold Water Behave in Warm Water?* Use the bottle you prepared for Experiment 26. Fill the bottle with cold water containing a few drops of ink. Put your finger over the hole in the stopper and turn the bottle upside down in the jar or bucket filled with hot water. (A wire fastened to the bottle as a handle will make it much easier to do this experiment.) Where does the cold water go? What goes into the bottom of the bottle?

EXPERIMENT 28. *Which Way Do the Cold Parts of Air Move?* (*a*) Plan some way of producing smoke or white fumes. Glowing punk, incense, joss sticks, or cotton cord will give small amounts of smoke. A bit of cotton wrapped about a stick and moistened in strong ammonia will cause white fumes when brought near a similar piece of cotton moistened with concentrated hydrochloric acid. Put some of the smoke or fumes near a cold window-pane or a block of ice or a cold brick brought in from outdoors.

b) If you have a refrigerator, open the door. Hold your hand just outside and below the opening of the refrigerator. Then hold your hand just outside and above the opening. Where do you find the cold air going? You may wish to hold a burning candle at the top of the refrigerator opening and then at the bottom to see which way the air is moving.

EXPERIMENT 29. *Which Way Does Warm Air Move?* Place some smoking material near a hot stone or brick, near a hot radiator or stove, or near any hot objects you can find. Which way does the air move?

If you will keep your eyes open, you will notice many, many examples of circulation similar to those in your experiments. Whenever you open an outside door in cold weather, the cold air pours in and flows along the floor, and warm air flows out the top. Most of the time there is

a little current of air rising around our bodies and carrying heat away from us. Scientists call all these currents in fluids *convection currents.*

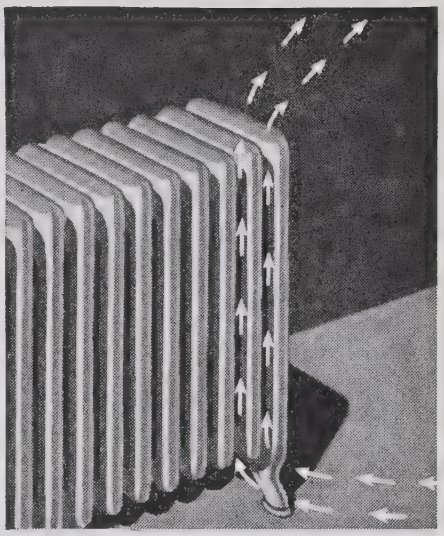


FIG. 168. Convection currents around a warm radiator

From the way hot air acts, people have come to say that, "Hot air rises." Most people have a feeling that the earth has actually lost its pull on the hot air and hot water that move upward. Careful study of what is really going on in such cases soon shows that air and water do not really lose weight when they are heated and regain it when they get cool. Can you explain what does happen?

HOW DO HEATING AND COOLING CHANGE THE DENSITY OF AIR AND WATER? To understand just why fluids circulate when they are heated, you must have clearly in mind what happens to the density of fluids such as air and water when they are heated and cooled. Does a bottle full of hot water weigh more or less than the same bottle full of cold water? If you are not sure of the answer to this question, you can make sure by doing a simple experiment.

EXPERIMENT 30. *Which Weighs More, a Bottle Full of Hot Water or the Same Bottle Full of Cold Water?* Get a milk bottle and fill it completely with hot water. (First warm the bottle slowly to avoid breaking it.) Cover the mouth of the bottle with a small piece of glass and see that there are no bubbles beneath the glass. Wipe off any water on the outside and place the bottle full of water on a balance (Figure 169).

Pour sand into a can on the other side (or use weights)

FIG. 169. Apparatus for Experiment 30

until the two sides are just even. Leave the sand or weights on the balance while you fill the bottle with cold water, cover it with the same piece of glass plate, and dry the outside. Put the bottle of cold water on the balance. What is the answer to the question of your experiment?

Here is another experiment that will help you to understand why heating water changes its density.

EXPERIMENT 31. *Why Is the Weight of a Bottle of Hot Water Different from That of a Bottle of Cold Water?* Fill a flask or a tin can with a small opening level-full of water. Be sure that there are no air bubbles at the top. Heat the water and watch the mouth of the vessel to see what happens. Continue heating until the water gets quite hot, but do not boil it. Then put a piece of glass over the mouth of the vessel to prevent evaporation and set it aside until the water becomes cool. Can you get as much hot water in a bottle as you can cold water?

When air or water is heated, the molecules bounce around more vigorously and knock one another farther apart. Thus, the molecules of a pound of warm water or

warm air occupy more space than when they are cool. If you put water or air into an open bottle and heat it, you can easily see that some of the fluid is pushed out as it becomes warmer. We say that the fluid expands. Thus a bottle filled with warm water weighs less than the same bottle filled with cold water. This is true not because the water has lost weight, but because we cannot get as much water in the bottle when the water is hot as when it is cold.

Of course it makes no difference whether you heat the water or air inside or outside a bottle. Whenever a substance is heated, it expands. It weighs the same, but it takes up more room. For this reason warm water is less dense than cold water, and warm air is less dense than cold air. People who do not know what density means usually say that hot water is "lighter" than cold water or that cold water is "heavier" than hot water. However, you know that a pound of water still weighs a pound after it is heated; it merely takes up more space.

Self-Testing Exercises

In each exercise you are to decide which word or phrase in parentheses makes the statement correct. In the first exercise you are also to supply a word for the blank space.

1. A gallon of warm water weighs (*more*) (*less*) than a gallon of cold water because water ..... when it is being heated.

2. When water is cold, you can get (*more*) (*fewer*) (*the same number of*) molecules in a bottle.

3. The density of hot water is (*greater than*) (*less than*) that of cold water.

4. The density of cold air is (*greater than*) (*less than*) that of hot air.

5. In hot water or hot air the molecules are (*closer than*) (*farther apart than*) in cold air or water.

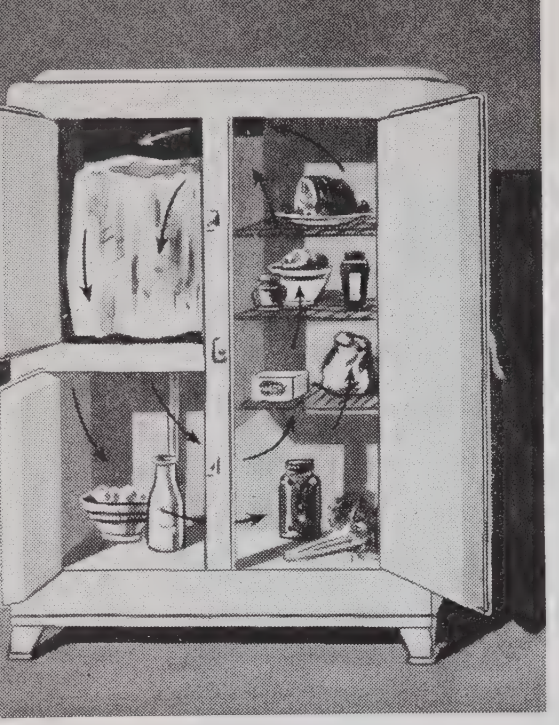


FIG. 170. The movement of air currents in one kind of refrigerator

WHY DO THE COLD PARTS OF WATER AND AIR MOVE DOWNWARD AND THE WARM PARTS UPWARD? In your experiments you have seen how warm water and air and cold water and air move. Probably you have already decided that these are just cases of floating and sinking like the ones you learned about in Problem 1. A cubic inch of warm water weighs less than a cubic inch of cold water that is near it. Gravity pulls the cubic inch of cold water downward harder than it pulls on the cubic inch of warm water. Therefore the cold water moves downward, flows under the warm water, and pushes it upward. The cold water sinks below the warm water; the warm water floats above the cold water.

In just the same way gravity pulls downward harder on a cubic foot of cool air than it pulls on a cubic foot of warm air. Because of the greater pull on it, the cold air moves downward and pushes up the warm air. You can find many places where this movement is going on.

But why does the air keep moving upward around a warm radiator or stove? This movement or circulation goes on because a new supply of cool air is constantly being heated. Just as soon as the cool air pushes the warm air up, the cool air itself gets near the hot iron. It gets warm, expands, and becomes less dense. Then the cool air around it can push it up. This happens over and over and keeps the air circulating so long as the radiator is warmer than the air around it. (See Figure 168.)

Much the same thing happens when something cold, like a block of ice, is placed in warm air. The air next to the ice is cooled by touching the ice. This air contracts and becomes more dense. Then gravity pulls it downward, and it flows under the warm air. This pushes the warm air up against the ice, where it, too, cools and sinks. Thus the circulation keeps up until all the air is as cold as the ice, or until the ice is all melted.

Why is the ice in an ice-box placed near the top? It is placed there so that the air in the refrigerator will be kept circulating until all of it is cold. Some warm air next to the cold ice gets cold and dense. Gravity pulls it down into the lower part of the refrigerator. Warmer air from the bottom is pushed up by the cold air and gets close to the ice. In turn it gets cold and sinks. If the ice were placed in the bottom, it would soon be surrounded by cold air that would stay close to it. The warm air that was pushed up would not be cooled. Thus only the lower part of the refrigerator would be cold. Food in the upper part would be warm.

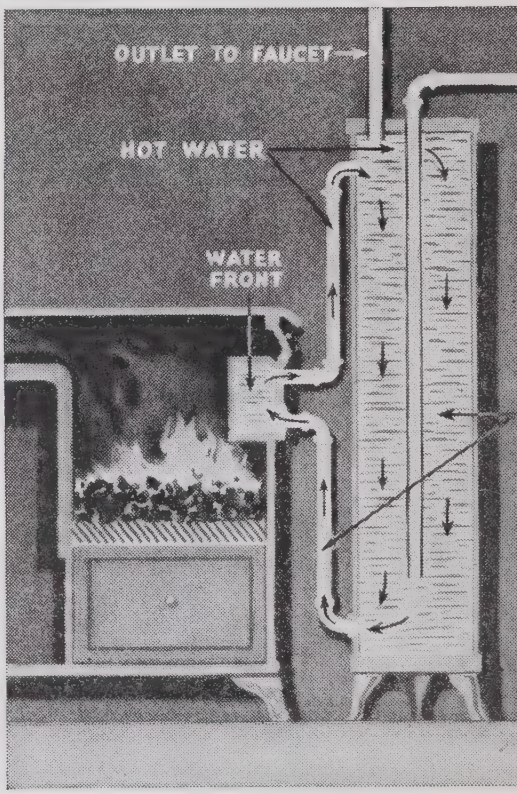


FIG. 171. A hot-water storage tank connected to a stove

Have you ever seen a hot-water storage tank like that shown in Figure 171? After the fire in the stove has been burning for a time, all the water in the tank is warm. How is this possible? The water in the waterfront gets hot from the fire. The water in the tank is cool and more dense. The cool water pushes down harder than the hot water. Therefore

the hot water is pushed up through the pipe into the top of the tank. Then a fresh supply of cool water goes into the water-front. As fast as the cool water flows in, it is warmed and gets pushed up by water that is still cool. Thus all the water in the tank passes through the water-front and is heated.

You have now learned that water and air do not really lose weight when they are heated. They do expand when heated, so that a cubic foot of space has less air or water in it when the material is warm than when it is cold. The warm material cannot push down so hard as the cooler material because it is less dense; therefore any air or water that is warmed is forced to move upward by the cooler air or water around it.

Self-Testing Exercises

1. The air around a warm object moves (*upward*) (*downward*), because cold air is (*more*) (*less*) dense than warm air.

2. Tell how the air next to a cold window moves and why it moves as it does.

3. Write down five examples that you have seen of warm air being forced upward and five examples that you have seen of cold air moving downward because of its greater density.

4. Explain why warm air keeps flowing up from a radiator as long as the radiator is warm.

5. Why is ice placed near the top of a refrigerator instead of near the bottom?

6. Explain how thirty gallons of water in a hot-water storage tank can get hot in a coil of pipe or water-front that holds only one-half gallon.

7. The door of a house is open on a very cold day. (*a*) Does the cold air come in at the top or at the bottom of the door? How do you know? (*b*) Where does the warm air go as the cold air comes in? Use a diagram if it will help.

8. Why is your school-room warmest near the ceiling?

Problems to Solve

1. When a fire is burning in a fireplace or furnace, there is a strong current of air moving into the fire and up the chimney. This current of air is known as the *draft*. Explain why the air moves up the chimney.

2. If a room is to be thoroughly ventilated, it is better to open windows at both top and bottom. Explain why.

3. Which would heat a room better, a radiator near the floor or one near the ceiling? Give the reason for your answer.

4. Draw a diagram to show how you think the currents of water would move in a large pan of water that is being heated in only one spot. Label the cold and the warm water.

5. Why is the draft in a chimney stronger after the chimney becomes warm?

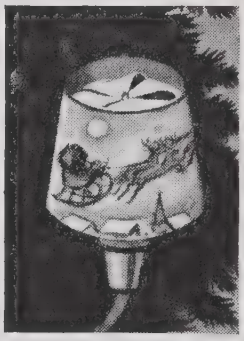


Fig. 172

6. A certain kind of Christmas-tree ornament has a little windmill in the top of it. The ornament is balanced on a needle point on top of a light bulb. It turns around as long as the bulb is lighted, but stops when the bulb is turned out (Figure 172). Explain why it does this.

7. The noted French inventor, Claude, needed a supply of cold water from the bottom of the ocean for one of his experiments in Cuba. After he had sunk a pipe, did the water flow up from the bottom, or did he have to pump it up? Tell why.

8. Explain why a balloon that is floating rises when the sun shines on it and sinks when it enters the shadow of a cloud.

LOOKING BACK AT UNIT 4

1. State Archimedes' Principle and explain what it means.

2. Give at least four good examples of the working of Archimedes' Principle. Show how it works in liquids, in gases, in ordinary floating, or loss of weight, and in convection currents. Explain each example briefly.

3. Explain or define each of these words:

fluid *displacement* *convection current*

ADDITIONAL EXERCISES

1. A good egg sinks in a jar of water. How can you make the egg come to the surface without touching it or the jar?

2. A boy weighs 125 pounds on some scales. His body displaces about 2.5 ounces of air. Do the scales tell his correct weight or make him weigh too much or too little? Explain.

3. While digging a canal, the workers found a large boulder below the surface of the water. The machinery they had was not strong enough to lift the boulder up to the top of the bank. The engineer in charge had a large place dug at one side of the bottom of the canal. The stone was then moved over out of the way without lifting it above the water. Explain why they could do that, although they could not lift it out.

4. At a school exhibit some boys had a tea-cup apparently filled with milk in which a ball of solid iron was floating. They would take the ball out and pass it around to show that it was as dense as iron. Yet when placed in the milk it floated. Explain how the trick could have been done.

5. A floating dry-dock contains large tanks that can be filled with either water or air. How would these be used to sink the dock and place it in position under a ship? How would the ship then be lifted out of the water?

6. In a common science experiment, water is boiled in a test-tube that contains ice. The ice is weighted so that it stays down in the bottom, and the water is boiled at the top. Why would the experiment not work if the ice were allowed to float on top of the water and the water were boiled at the bottom?

7. Explain in terms of density of different parts why the test-tube of Experiment 25 floated on end.

8. Good eggs sink to the bottom of a jar of water, but spoiled eggs float. Which kind is more dense?

9. Good eggs float in a concentrated solution of salt. What does this show about the density of the salt solution?

10. How could you perform an experiment to discover how much weight a life preserver will support in water?

FIG. 173. When our country was first settled, almost all work had to be done with energy of muscles—the muscles of men and of animals. Today, in the home, on the farm, and in the factory we use kinds of energy about which the early settlers knew nothing. Even fifty years ago men did not know about the energy that makes this tractor run so that it can furnish the power to thresh wheat, blow the straw on to the stack, pull plows, and in other ways make things move. In this unit you will learn some of the important things that man had to discover about energy before he could know how to use it.

UNIT FIVE

UNIT 5

HOW DO WE USE ENERGY?

INTRODUCTORY EXERCISES

*1. What is the molecular theory of matter?

*2. Does a magnet have energy? Explain why you think it has or has not.

3. What is energy?

4. Make a list of things that energy does for you every day.

5. What is inertia? Give some examples of inertia.

6. Define friction and give some examples of friction.

*7. What is heat?

*8. Make a list of the changes that heat can cause in materials.

9. How many different kinds of energy do you know? Name them.

*10. What are the different kinds of matter?

*11. Where do we get the energy that enables us to move our bodies? How is this energy made usable in our bodies?

12. How is energy different from matter?

13. What are some of the different things that energy can do to matter? List as many different things as you can.

14. When and where have you noticed one kind of energy change into another kind of energy? Give three instances if you can.

LOOKING AHEAD TO UNIT 5

FIG. 174

SOME BOYS were playing ball in a vacant lot. Bob stepped to the plate, and the pitcher threw the ball swiftly across the plate. Bob swung his bat as hard as he could and struck the ball squarely. The boys on both sides held their breath as the ball flew through the air. Then, crash! It broke a neighbor's window, and the glass fell tinkling on the walk. Why could the ball break the window?

The tall "grandfather's" clock in the hall had stopped. Mary took a little crank from a shelf and placed it in a hole in the face of the clock. Then she turned the crank round and round until a heavy iron weight inside the case had been lifted from the bottom almost to the top. Next, she set the hands in the right place and started the pendulum swinging. The clock ran for more than a week. During the week the weight sank lower and lower until it again reached the bottom of the case. Again Mary had to lift the weight to the top by winding it up. What did Mary do to the weight that helped it run the clock for a week?

A huge cold locomotive stood in its stall in the roundhouse. The men who were repairing it wanted to move it a short distance. Two of them took heavy crowbars and by prying against the wheels were able to move the great

FIG. 175. The sun shone down on a wide concrete pavement on the hottest day of summer. Suddenly a part of the pavement broke, and the pieces on each side were tilted up and left leaning against each other with jagged cracks running in all directions. What was there in the sunlight that could break the thick concrete and make it push itself up into the air?

machine a few inches. When the repairs had been finished, a man started a fire in the fire box of the locomotive. Slowly the great locomotive began to come to life. Little clouds of steam escaped here and there with a gentle hiss. The needle on the steam-pressure gauge went farther and farther around until it stood at 150 pounds per square inch. Then an engineer moved some levers, and the locomotive backed out of its stall with ease. Soon it was coupled to a freight train of nearly 100 cars. The powerful engine pulled the train for many miles at a speed of more than thirty miles an hour. What did the engine get from the fire that gave it the power to pull the train?

Can you answer each of the questions that have been asked? The answer is the same for all of them! And can you explain how the baseball, the clock weight, the con-

crete in Figure 175, and the locomotive could do what they did? If you study the four problems of this unit carefully, you will learn the answers to all these questions. And you will be able to explain many other things that you see happening every day.

Problem 1:
WHAT IS ENERGY?

ONE MORNING John arrived at school early and hurried up to his science room. He had a question to ask Mr. Kendrick, his teacher. Mr. Kendrick had come early, too, and was getting an experiment ready for his first science class.

"Mr. Kendrick," said John, "last year you told us that everything is made of matter. Then we learned that matter is anything like water or wood or air that has weight and fills up space. I've heard people talk about energy, and last year we studied a little about heat energy and about energy in coal and wood and food. Is energy just another kind of matter, or is it something different that you haven't told us about yet?"

"That was quite a speech for you," said Mr. Kendrick, with a smile. "I see that you have been doing some thinking. It's just about time we all learned something more about energy. Let's talk about energy in our science class today. Until then, you might be trying to decide whether energy and matter are the same. Suppose that you try to figure out whether heat has weight and occupies space."

As John went down the hall, he said to himself, "Does heat weigh anything? It's funny I never thought about that before. I always thought things got lighter when they got heat in them. Does heat fill up space? Well,

it goes right into iron and steel and water. And when it goes into them, they all expand. We learned that last year. Maybe it does fill up space and make things bigger. I wonder!"

In your science work last year, you learned many things about matter. You learned that it has weight and fills space. You learned that it is made of tiny little particles, called *molecules*, much too small for us even to imagine. You also found that matter seems to change from one substance to another during chemical changes. It seems as if we could explain almost everything in the world by talking about matter.

But what are you going to call heat and light and sound? Are they matter? What makes things move and expand and evaporate and change chemically? To explain what we see going on every day, we must believe there is something besides matter in the world; there must be something that makes matter do things, that makes matter change. We call this "something" *energy*. We cannot weigh energy; we cannot prove that it fills space. Yet we can sometimes feel energy and sometimes see it and see the things it does.

Last year you met energy several times in your study of science. You learned that it is heat which makes matter expand and melt and evaporate. Heat also helps chemical changes to take place as it did when you changed coal into coke and gases. You learned that food contains energy which we use to move and to keep our bodies warm. You learned that sunlight, shining on the leaves of green plants, furnishes the energy to change carbon dioxide and water into sugar. Where else can we find energy doing things to materials?

Whenever matter is able to make things happen, we

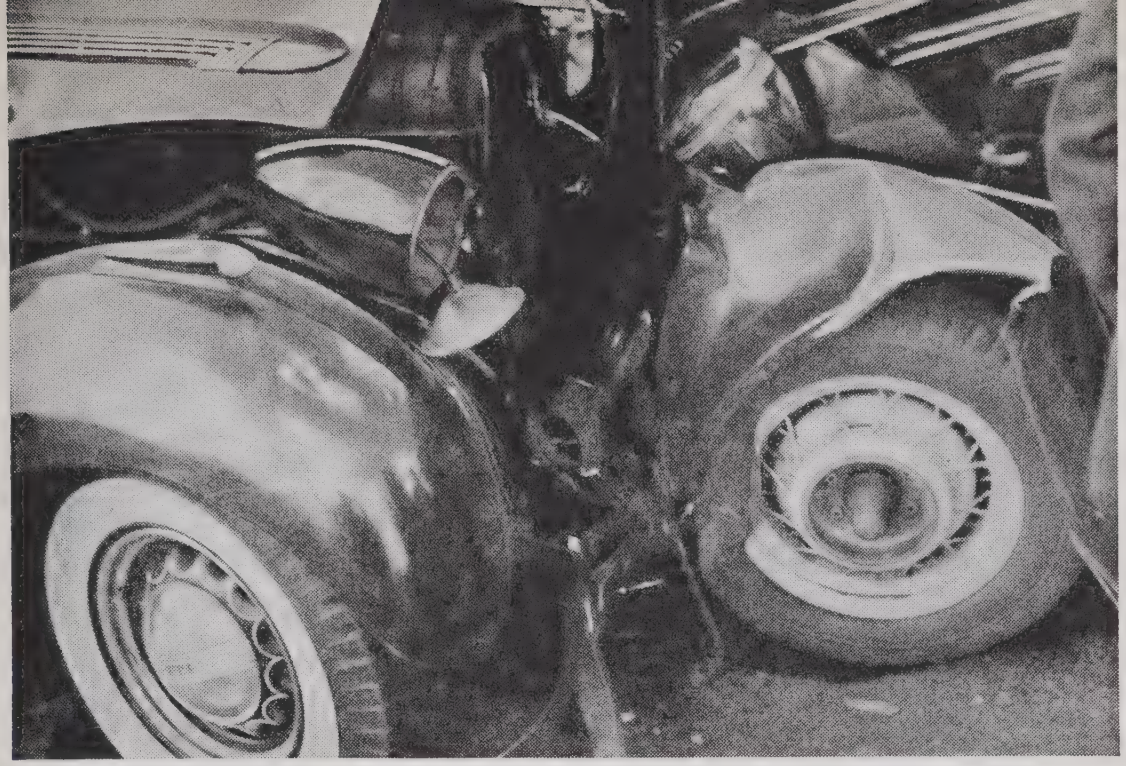


FIG. 176. An automobile moving swiftly along a road has tremendous energy because it can break down a fence or post and smash another car, or even knock it off the road.

say that the matter has energy. A bent bow has energy because it can shoot an arrow. Running water has energy; it can move soil and rocks and turn water-wheels. A heavy weight held up by a rope has energy because it can drive a stake into the ground or crush a stone when it falls. The powder in a rifle cartridge has energy; it can drive a bullet through a board. You can easily see that many of the bodies of matter around you have energy.

WHAT IS A FORCE? You have just read a description of energy that gives you a general idea of what it is. But this description is not good enough for scientists because it is not quite exact and accurate enough for their use. Scientists must have exact and accurate meanings for words, or they cannot think and talk accurately about the problems they have solved and are trying to solve.

Before you can understand fully what energy is and does, you must have some other ideas that are all a part of the big idea of energy. First of all, you will need to know something about *force*.

Every time you pick up a book, push your feet against

the pedals of your bicycle, open a door, or write in your note-book, you are using a force. If you will think about all the times when you use a force, you will find that you do one of two things: You either push some object, or you pull it. Of course, sometimes you do both. For example, in steering an automobile you may pull the wheel with one hand and push with the other. Whenever you make something move, you use a force. But you may use a force without making anything move. You have probably pulled or pushed some heavy object without being able to budge it. If you pull or push an object, you are exerting a force, regardless of whether or not you move the object.

So far you have been thinking about the force that human beings can exert by the use of their muscles. There are, however, other forces in action around you all of the time. If you stand in an open place on a windy day, you quickly feel the force of the wind pushing against you. Similarly, if you stand in a swift stream of water, the force of the water pushing against you may throw you off your feet. If you step off a high porch, the force of gravity pulls you down to earth. If you make a deep dive, you can feel the force exerted by the weight of the water above you. You know that magnets exert force to attract bits of iron and steel. Whenever you see anything move, you may be sure that it is pulled or pushed by some force.

WHAT IS WORK? You made a start toward learning the meaning of energy when you found out what a force is. But before you can fully understand the meaning of energy, you must also learn what the scientist means by the term *work*. This is a common word. You probably think that you know very well what it means.

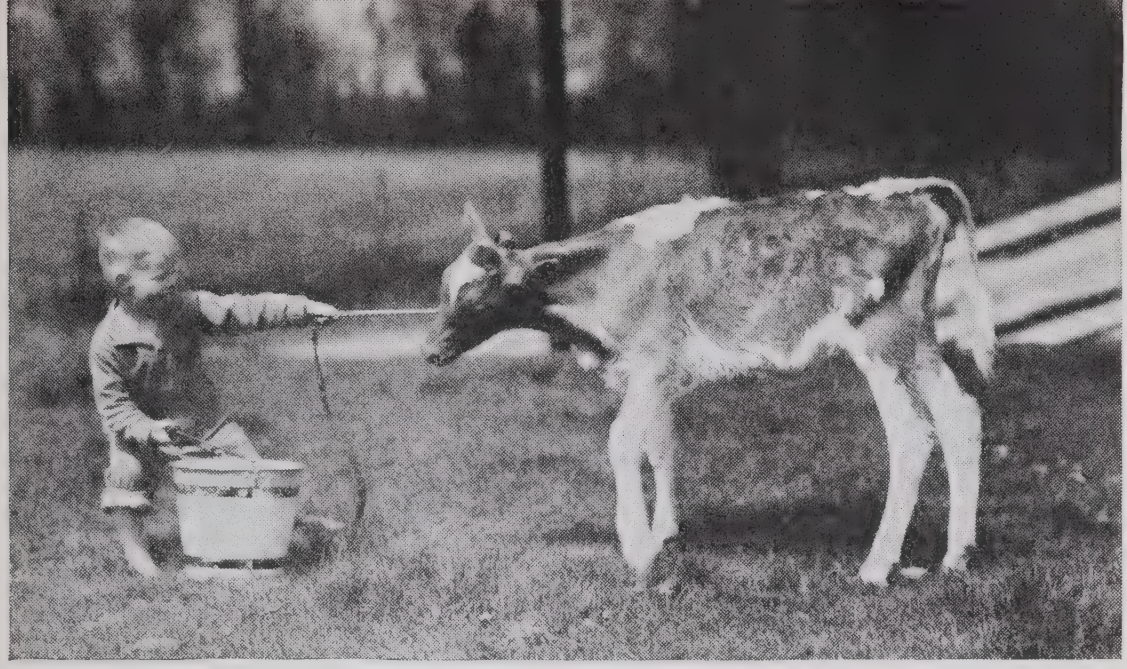


FIG. 177. This little chap probably thinks that he is working pretty hard, but a scientist would say that he is not doing any work because he cannot make the calf move.

Work to you is something that you have to do but do not enjoy doing. Like many other words, work has several meanings. In connection with energy, scientists use a special meaning for this word.

If you push as hard as you can against a table and do not move it, you have done no work, according to the scientist. On the other hand, if you move the table, you have done work. In other words, to a scientist work is not done unless the object is moved. When you lift a book from the table, push a lawn-mower across the grass, pedal a bicycle, climb the stairs, or drive a tent pole into the ground, you are doing work. In each case you exert a force, and as a result something moves. That is, work is done when a force is used to overcome some resistance and thus move something.

HOW DO SCIENTISTS DEFINE ENERGY? Now we are ready to consider the meaning of the word *energy*. Here again is a word for which scientists use a special meaning. Energy, to the scientist, means *the capacity to do work*. Work, as you already know, is done when a force moves an object. Therefore, a body is said to possess energy if it can move an object.

You can understand this better through a few examples. Does a bent bow have energy? Yes, it can drive an arrow through the air. Does running water have energy? Yes, it can turn the blades of a water-wheel. Does a heavy weight suspended by a rope in the air have energy? Yes, if it is dropped, it can drive a stake into the ground. Does a rapidly moving ball have energy? Yes, if it strikes a window-pane, it will break it. You see from these examples that if a body can do work, it possesses energy.

To say that something can do work is really just another way of saying that it can make things happen. The real advantage of the scientist's definition is that he knows how to measure work. If he can measure the work that energy does, then he can measure the energy. Later you will learn how scientists measure work and energy.

Self-Testing Exercises

1. Write a paragraph of not more than one-half page in which you answer the question, "What is energy?"
2. Give at least three different examples of the effects of energy.
3. What is a force? Give three examples.
4. What is work? Give some examples of doing work in the scientific sense.
5. Answer the questions in the first three paragraphs of "Looking Ahead to Unit 5" and in the legend under Figure 175.

Problems to Solve

1. Make a list of at least ten examples of the effects of energy that you have noticed but that have not been mentioned in the book.
2. Write a short composition on "The Importance of Energy."
3. Give five original examples of doing work. Thus you may put down, "*I lifted my body upstairs to class.*"
4. What force turns a compass needle to make it point north?

FIG. 178. Much of the work of the world is still done by the muscles of men, but other sources of energy enable man to do things that he could never do with his muscles. Men can drive stakes with sledge hammers, but they cannot drive a great pile into the earth, as the pile-driver is doing in Figure 187, page 243.

5. An automobile was stuck in a mud hole. A farmer brought a horse and hitched it to the car. But try as it would, the horse could not move the automobile. Then two horses were hitched to the car and pulled it out. Did the first horse do work? Did the two horses do work? Explain your answers.

Problem 2:
WHAT DO WE DO WITH ENERGY?

YOU HAVE now learned that we use energy whenever we do work. Think of all the different kinds of work that need to be done in the world. Wagons, automobiles, trucks, and trains with their loads are to be moved. Soil must be plowed and cultivated so that the crops will grow. Rocks and soil must be moved out of excavations for basements, highways, and tunnels. Material must be lifted into place to make new buildings. People, furniture, machinery, and supplies must be carried up when the buildings are in use. Grain and cement must be ground, rock must be crushed for roads, and lumber must be

FIG. 179. One boy gives the sled a push to start it moving downhill. This force is needed to overcome the inertia that makes an object stay where it is.

sawed from logs. You could go on for a long time adding examples of work to this list.

However, scientists are not much interested in getting long lists of examples of different kinds of work. What they want is to find out how the different kinds of work are alike. Of course, all the examples given above are alike because forces are used to move something. But notice that there is always some resistance to be overcome. In fact, one way scientists define work is to say that it is the overcoming of resistance. When we do work, we must use one force to overcome another force that resists our action.

As scientists have studied all the different kinds of work, they have found that most of it is done in overcoming four different kinds of resistance. These four kinds are the resistance due to *inertia*, to *friction*, to gravity, and to the forces that hold the molecules of matter together. Let us now see how each of these kinds of resistance acts.

WHAT IS INERTIA? Suppose that there is a book on the table in front of you. It stays there so long as it is not pulled or pushed. In other words, it will not move unless it is acted upon by a force. The book will not move because of a certain *property*, or characteristic, that all matter has. This property is called inertia. Inertia is rather hard to understand, but a few examples of inertia will help to make it clear to you.

Perhaps you have had the experience of trying to

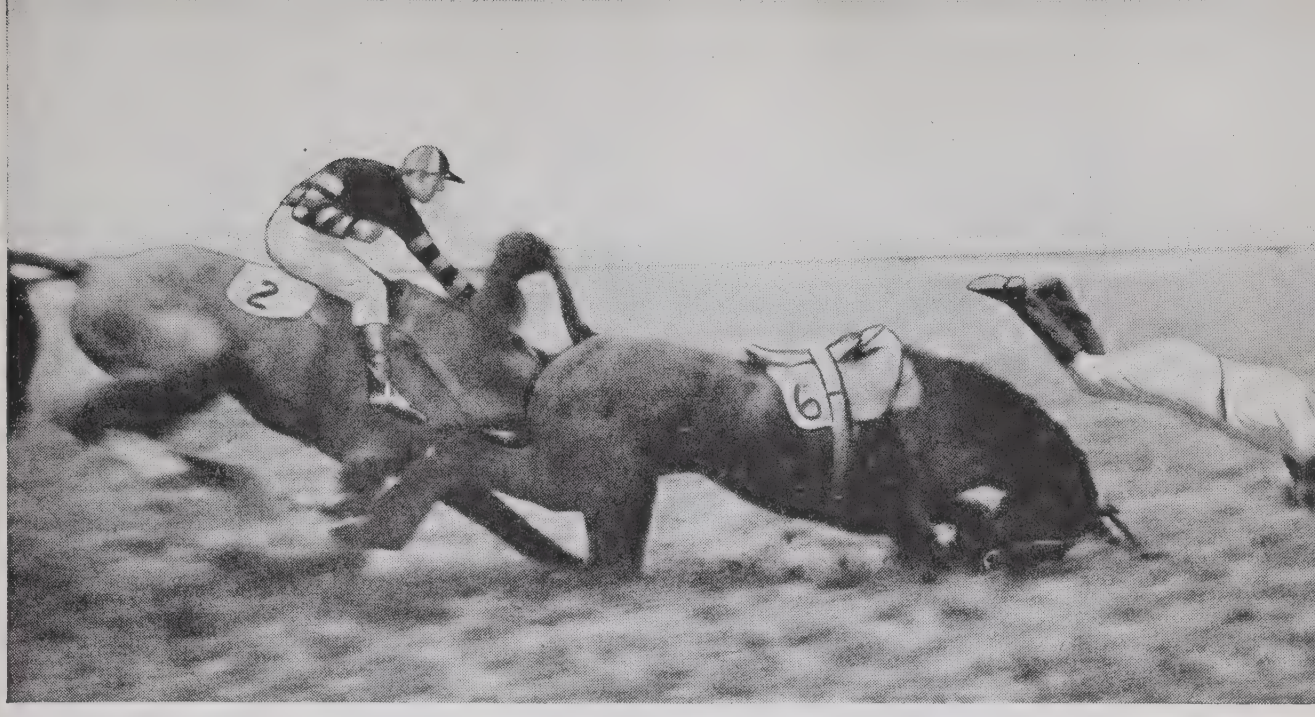


FIG. 180. The horse and the rider were moving forward in a straight line. The horse fell and stopped. The inertia of motion sent the rider flying forward over the horse's head.

move a stalled automobile. You push and push, and nothing happens. Someone comes along and helps you, and finally you get the car moving. After you once get it moving, it is easy to keep in motion. The hard part is to get it started. The reason is that you must overcome the inertia of the car. A great deal of force is required to do this.

We can say that objects resist being moved. You could prove this to yourself in a rather painful way. Hang up a brick on a strong cord and strike it a hard blow with your fist. The result will be a badly injured hand caused by the inertia of the brick resisting motion. These two examples should convince you that stationary objects have inertia; that is, they remain stationary unless some force moves them. To overcome this inertia a force is necessary.

Forces are needed to overcome another effect of inertia. Suppose you are riding in an automobile that is going forty-five miles an hour. The automobile with you inside it is moving forward in a straight line. Suddenly a "stop light" looms up ahead, and the driver slams on the brakes. The car slows down quickly because a force

FIG. 181. If you have ever watched the "hammer-throw," you have seen inertia and centrifugal force at work. As the thrower swings the hammer round and round in a circle, it pulls harder and harder. When he lets go, it flies off in a straight line.

has been applied to stop it. But what do you do? You tend to keep moving ahead, and the result is that you are thrown forward and may even go off the seat.

What automobiles and trains really should have is some kind of brake to attach to the passengers so that they will be slowed down when the car brakes go on. Passengers in airplanes really do have brakes. They are required to attach a safety belt across the seat to resist the inertia of their bodies when the airplane starts or stops or when rough air is encountered.

These illustrations show you a second effect of inertia—the inertia of moving bodies. Objects that are moving tend to keep on moving in a straight line unless some force stops them or changes the direction from a straight line. You can see that forces are needed to overcome the inertia of a moving object, that is, to stop the object or to change the direction in which it is moving.

When things go around in a circle very rapidly, it is

easy to see or to feel how inertia works. Take a ball on a string as an example. Hold one end of the string and whirl the ball around rapidly. The ball seems to be trying to get as far as possible from the center around which it is whirling. It may even break the string and go flying away. The force that makes the ball pull away from the center is called centrifugal force. It is really caused by inertia that tends to make the ball move in a straight line, which it cannot do because the string makes it move in a circle.

FIG. 182. The inertia of moving objects shoves the coal forward many feet when the shovel is suddenly stopped.

All whirling objects have centrifugal force. Centrifugal force throws mud and water off the wheels of bicycles and autos. It throws your arms out from your sides when you spin around rapidly. It sometimes bursts grinding wheels that are turned too rapidly. You can see the action of centrifugal force almost every day. Remember that centrifugal force is just the inertia of things that are being made to move in a circle instead of in the straight line that they would follow if they were free.

You use the inertia of moving objects in many ways, for example, in shoveling coal into a furnace. You fill the shovel with coal and swing it quickly toward the open furnace door. This makes the coal move, as well as the shovel. When your shovel reaches the door, you stop it, but the coal keeps on going into the furnace (Figure 182). If it were not for the inertia of the moving coal, the coal would stay in the shovel.

It is also true that moving objects can exert force because of their inertia. Thus, a moving automobile can bend the parts of another automobile or break a post in two because the automobile tends to keep on going.

You have learned a number of important things about inertia, but you still cannot answer this question: "Why does a moving body or a stationary body possess inertia?" No one knows the answer to this question. We merely know that all objects do have inertia. If a body is standing still, some outside force must act upon it to make it move; otherwise it will remain stationary. If a body is moving, some outside force must act upon it to slow it down and stop it; otherwise it will keep on moving. If we could not exert forces, we could not move stationary objects or stop or change the direction of moving objects.

FIG. 183. The tread on tires helps to prevent skidding by providing greater friction between the wheel and the ground.

WHAT IS FRICTION? You have seen that we need forces to make stationary things move because inertia keeps them from moving. We also need forces to stop moving objects because inertia keeps objects moving unless something stops them. There is another reason why we need forces to move things. Friction makes it hard for them to move. Let us see what friction is.

Whenever two materials are rubbed together, there is friction between them. You can slide easily on ice or on a waxed floor, because there is little friction. But if you try to slide on a concrete sidewalk or a rough board, you fail. These rougher materials offer more resistance to

the force of your slide; that is, there is much friction between you and the material.

An automobile moving along a level road is soon stopped by friction if the engine is shut off. A wheel of an automobile revolves on an axle. The axle and the hub rub against each other, producing friction. Furthermore, there is friction between the tires and the pavement. And last of all, the air offers resistance to the car as it pushes its way through the molecules. Because of these kinds of resistance, the car moves more slowly and finally comes to a stop. The inertia, or tendency of the car to move forward, is overcome by the resistance of friction and of air. If the car is to be kept moving forward, energy from the engine must be used to overcome friction and the resistance of the air.

HOW DO WE OVERCOME GRAVITY? Of course you know that it takes force to lift an object. This is necessary because of the pull of the earth on the object. This pull of the earth is called gravity. Here, then, is another reason why we need forces to make things move. Without forces, we could not lift things off the earth or move them uphill. For example, you have a sack of flour that weighs ten pounds. This means that gravity exerts a force of ten pounds on the flour. If you wish to lift the sack of flour, you must exert a force of more than ten pounds.

Up to this point you have seen that forces are necessary (1) to overcome the inertia of bodies at rest (starting an automobile), (2) to overcome the inertia of moving bodies (stopping an automobile with brakes), (3) to overcome the resistance offered by friction and by air, and (4) to overcome the force of gravity. There is another kind of force that is important.

WHEN DO WE OVERCOME THE FORCES OF MOLECULES? You can tear a fairly heavy piece of cardboard or push your hand down into a jar of water. You can do these things because of the way these kinds of matter are made. You cannot, however, tear even a very thin piece of steel, and of course you cannot push your hand into a bar of steel. This seems to call for an explanation. As you know, scientists believe that all matter is composed of tiny particles called molecules. These molecules are so tiny that the smallest bit of matter you have ever seen is made of millions of them. When you tear a piece of cardboard, you must pull the molecules apart along the line of your tear. Some force is needed to do this. Force is needed because the molecules of the same kind of substance have an attraction for each other; that is, there is apparently some force that holds them together. This is called the *force of cohesion.*

In some substances, such as paper and water, the cohesive force exerted by the molecules is very slight; and only a small force is required to pull them apart. In other substances, such as glass and steel, the cohesive force is very great; and a great force is needed to pull the molecules apart. The cohesive force between molecules differs in different kinds of materials. When you pull a substance to pieces, tear it in two, saw it, or cut it with a knife, you need force to overcome the cohesive force of the molecules.

There is also a very similar force called *adhesion.* The attraction between molecules of different kinds of substances is called the *force of adhesion.* When glue holds two pieces of wood together, the force of adhesion between the molecules of glue and the molecules of wood holds the wood and the glue. The adhesion of the molecules of ink

to the molecules of paper makes the letters stay on the page so that you may read them. When you write with a pencil, the friction between the paper and the carbon ("lead") of the pencil rubs off a little of the carbon. The carbon sticks to the paper because of the force of adhesion.

You have seen that the forces of cohesion and adhesion are necessary to hold materials together. Without them, molecules would not stick together, and solid and liquid substances as we know them would not exist. Many times we need to use energy to overcome the forces of cohesion and adhesion.

FIG. 184. Adhesion makes paint stick to a car when it is sprayed on or put on with a brush.

Self-Testing Exercises

1. Why does it require more force to start a body moving than it does to keep a body moving?
2. Why do moving objects stop moving unless a force is constantly applied to them?
3. What are the two effects of inertia?
4. What is centrifugal force? Give an example.
5. Why do brakes stop a car?
6. What is the difference between cohesion and adhesion?
7. Name at least four kinds of resistance that we overcome by using energy.

Problems to Solve

1. What kind of force causes the varnish to stay on a chair?
2. Explain why a hammer would be useless without inertia.
3. Can you turn a pail of water upside down without spilling the water? You can do it by swinging the bucket rapidly

in a circle that goes above your head and down toward the ground. Why does the water not spill from the pail?

4. Why does a car often skid if it turns the corner too fast?

5. Lay a strong sheet of paper on a table. On one end of the paper put three or four books. Take a firm hold of the exposed end of the paper and give it a quick jerk away from the books. What happens? Explain.

6. How does inertia help in shaking apples from a tree?

7. Why does it cost much money to start or stop a fast train?

8. Why does it take more power to start an automobile that is standing in mud than one that is standing on a pavement?

Problem 3:

WHAT ARE THE DIFFERENT FORMS OF ENERGY?

In a science class where work, force, and energy were being studied, one of the boys raised his hand one day and said this to the teacher: "I think I can tell when energy is at work making things happen, but there's one thing I don't quite understand. You've been talking about heat and light and other things, and calling them all energy. Are there different kinds of energy, just as there are different kinds of matter?"

Perhaps that question has come up in your mind, too. It is an important question. It is a question about which men have been thinking for hundreds of years. They have been thinking about it because they needed energy to help them do their work. Before they knew how to use the energy that was everywhere around them, they had to do all their work with the energy of their bodies, and that energy came from the food they ate. They had nothing else to help them lift, pull, push, throw, hammer, and cut materials.

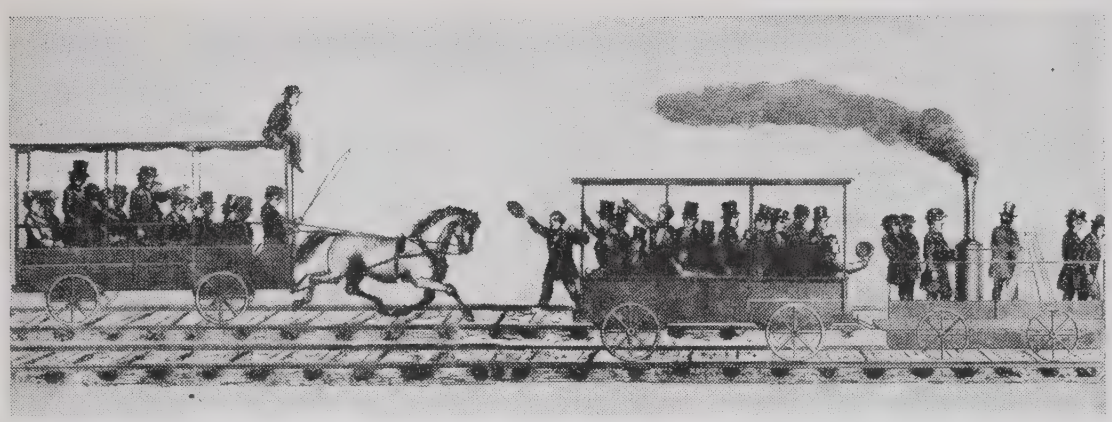


FIG. 185. In the early days of the railroad, about 100 years ago, a race was staged between a "horse train" and an "engine train." Men still had little confidence in steam as a source of energy for moving people and materials. At first the engine pulled ahead; then it broke down, the horse won the race, and men said that the steam locomotive would never amount to anything.

You can easily see that we would be living in a quite different world today if men had not learned how to use other kinds of energy than the energy of their bodies. Human energy could not possibly make heavy airplanes fly through the air for thousands of miles at hundreds of miles per hour. Human energy could not easily move great freight trains for hundreds of miles. Human energy could not blast out great blocks of rock in the flash of an eye. If we had to depend on the energy of our bodies, we could not take pictures with a camera, send radio programs over the air, and have electricity for lighting —to say nothing of countless other things that are every-day matters to us. Let us see what some of the kinds of energy are.

You have already learned many things about one of the forms of energy that is all around us, namely, *heat energy*. You know that heat makes substances expand and that it can change water into steam. Another form of energy that you know about is *electric energy*. Probably

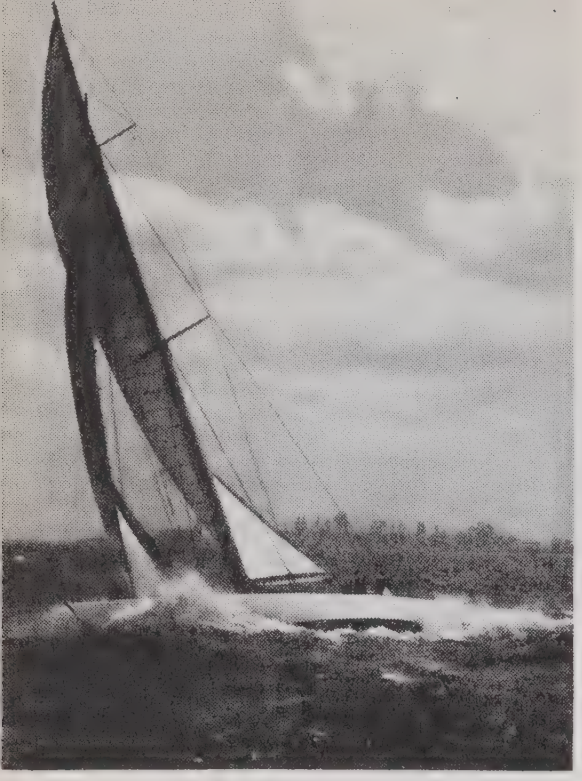


Fig. 186. Moving air has kinetic energy. When it strikes the sails of a sailboat, it makes the boat move.

you use it almost every day. The energy of electric current starts our automobiles, explodes the gasoline to make them run, operates our telephones, street-cars, fans, mechanical refrigerators, and vacuum-cleaners. Probably half of the work done by machinery in the factories of this country is done by electrical energy.

WHAT IS MECHANICAL ENERGY? The energy in running water, in a speeding automobile, in a bent bow, and in a lifted weight is called *mechanical energy.* It is called mechanical energy because it is the kind of energy that is used in machines. Now notice that in two of the examples of mechanical energy something was moving. A rapidly flowing stream can move large rocks and turn a water-wheel just because of the movement of the water. An automobile can do damage because it is moving. Thus you can see that one kind of mechanical energy is the energy of motion. Scientists call this kind of energy *kinetic energy.* All moving objects and moving materials have energy of motion, or kinetic energy.

Think for a moment and see if you can find some other examples of kinetic energy. When a bat strikes a ball, part of the kinetic energy of the moving bat is given to the ball, and the ball moves away from the bat. When a hammer strikes a nail, part of the kinetic energy of the moving hammer is given to the nail, and the nail is forced in between the molecules of wood. When moving air strikes the blades of a windmill, the air causes the

wheel to turn. A rock rolling down a hillside strikes other rocks and sends them rolling, too. Everywhere you go, you see moving objects doing things. They can do these things because every moving object has kinetic energy.

It is easy to see that any moving body of material has energy, because it can make other things move. But there is another kind of mechanical energy that may not be so easy for you to see. Think for a moment about the kind of energy that is in a bent bow, a wound-up spring, and a suspended weight. You know that these three objects do not have kinetic energy because none of them is moving. But they have energy even though the energy is not doing anything.

FIG. 187. A pile-driver uses the energy stored in a weight when the weight is lifted from the earth.

Think first of the heavy weight hanging from a rope. If you cut the rope or untie it and let the weight fall, the weight surely has energy. The energy was there all the time waiting to be used. As a matter of fact, the weight was pulling hard on the rope. It had energy because it was above the surface of the earth. Any object that is lifted above the earth has energy stored in it. We know it has energy because it can make something happen when it is allowed to fall to the ground. This energy was stored in the weight when it was lifted. It can be turned loose and used when the weight is allowed to fall toward the ground. Scientists speak of stored mechanical energy as *potential energy*. You may call it either stored energy or potential energy.

FIG. 188. The muscular force of the men overcomes the elastic force of the bows. The bow at the left is made of wood; the bow at the right is made of steel.

Have you ever seen a pile-driver at work? A steam-engine or some other source of power lifts a heavy weight. The energy used in lifting the weight is stored in the weight. Then the weight is dropped on the post (called a "pile") beneath it, and the post, or pile, is driven into the ground. The energy of the weight is used in forcing the post into the soil. Then more energy is stored in the weight by lifting it again, until the post has been driven into the ground as far as necessary.

Now think about the energy of the bent bow. When you pull back on the bowstring, you overcome the resistance of the bow to being bent. That is, you do work on the bow and change the positions of its parts with reference to each other. But the bow is *elastic;* it can spring back into its first position again. As it does so, it can overcome the inertia of the arrow and send the arrow flying toward the target. Energy was stored in the bow when you did work in bending it. The energy was given out again when the bow was released.

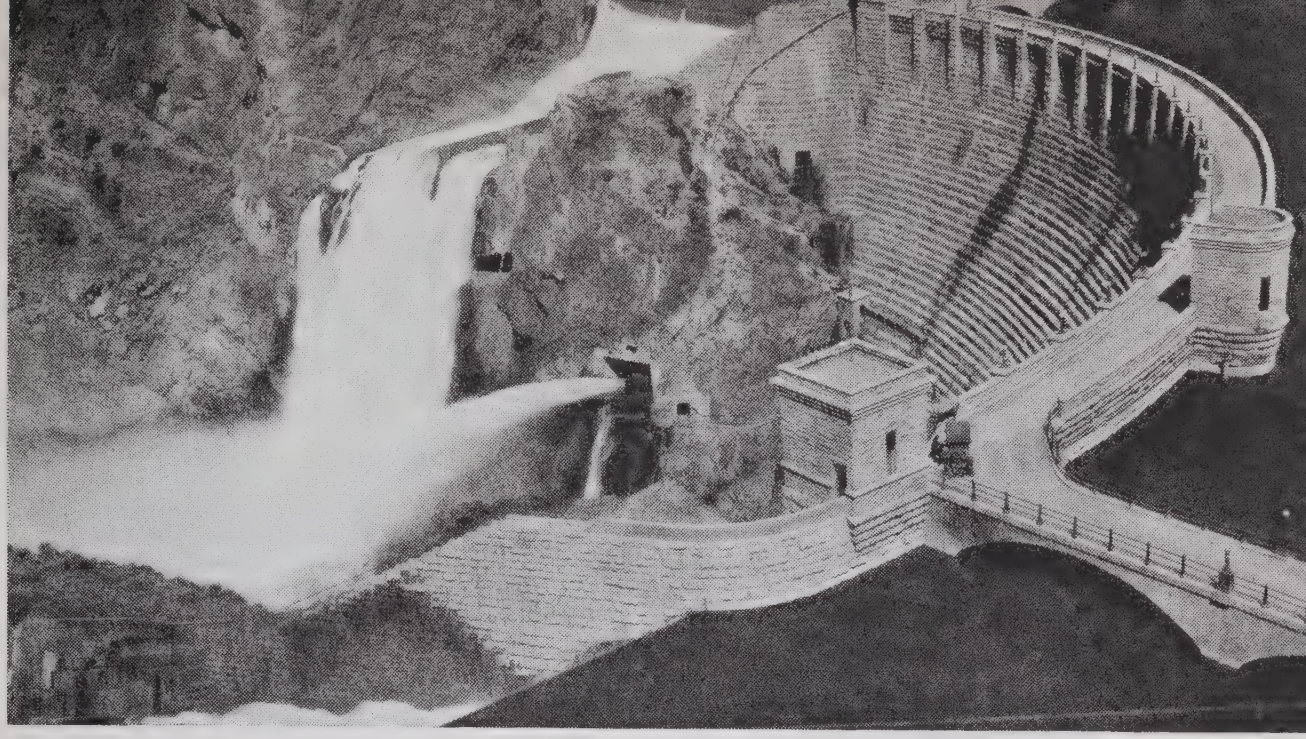


FIG. 189. The water at the top of the dam has stored-up, or potential, energy. As it falls, it changes to moving, or kinetic, energy, which can do work.

You also make frequent use of energy stored in springs. Among other things, you use springs to close doors after you have gone through them, to run watches, and to roll up window shades. Whenever you bend, "wind up," or twist a spring, you are doing work on it and are storing potential energy in it. Then, when you release it, the spring gives out the energy, as in closing a door, running a watch, or rolling up a window shade.

Now let us sum up what you have learned. Two common kinds of energy are called mechanical energy because we usually see them at work in machines. The first of these is the energy that objects have when they are moving. Scientists call the energy of motion kinetic energy. The second kind of mechanical energy is stored energy, or potential energy. Objects have potential energy because of their position. They may be lifted up from the surface of the earth so that they can fall, or they may be stretched, bent, or twisted, as in the case of springs, so that they can do something when they are released.

FIG. 190. The chemical energy in different kinds of explosives is used in shooting bullets through the air, in blowing stumps out of the ground, and in blasting away rocks and soil.

WHAT IS CHEMICAL ENERGY? You have seen chemical energy at work many times, but of course you did not think of it as energy because you did not know what energy is. But now you know that energy is what makes things happen to materials. With that idea in mind, think for a moment about the energy that is released when materials change.

When you light a fire-cracker, there is a quick sputter as the fuse burns, followed by a terrific bang. The tough paper of the fire-cracker is burst open. A tin can placed over the fire-cracker flies high up into the air. Surely there is energy in the powder in the fire-cracker, but a chemical change has to take place before the energy can be let loose. That chemical change takes place when the powder burns. Coal, too, contains chemical energy. When coal combines with oxygen in a fire (a chemical change), the chemical energy is released and does many useful things for us. We release chemical energy from gasoline to run our automobiles, trucks, and tractors. Our bodies

move and keep themselves warm by using the chemical energy of food.

Thus you see that chemical energy is so important that we could not live without it. Chemical energy is a kind of stored energy. It is sometimes called chemical potential energy. It cannot be used unless there is a chemical change in the material in which it is stored.

WHAT IS RADIANT ENERGY? Last year when you studied how plants make food, you learned that light from the sun provides the energy with which the green plant changes carbon-dioxide and water into sugar. Light, then, must be a kind of energy because it can make things happen to matter. Probably you have used light energy in a way that is very interesting to you. You may have taken pictures with a camera. When you did this, light energy changed the film to give you the picture (Figure 191).

Light is different from the other kinds of energy about which we have learned because it can leave the material from which it comes, shoot through empty space or through air, and cause changes in things a short distance away or millions of miles away. For example, the light of the sun shoots across more than ninety million miles of space to the earth where it helps us see, provides the energy to make food in green plants, and does many other things. Light from a lamp or a fire travels to objects many feet or even many miles away.

There are other kinds of energy that act like light, but we cannot see them. You may have heard of some of these varieties of invisible energy. Radio waves, X-rays, ultra-violet rays, and infra-red rays (also called *radiant heat*) are kinds of energy. They all can make things happen to matter. Scientists have a special name for all the energy

FIG. 191. The energy of light changes the materials in a film every time you take a picture. This is the negative of the picture.

that acts like light by shooting out in straight lines or *radiating* through space. They call it *radiant energy.* Radiant energy is thus another form of energy we have learned about. Light is just one variety of radiant energy.

Self-Testing Exercises

1. Name the six forms of energy mentioned in this problem.

2. What are the two forms of energy that are called mechanical energy? Give an example of each kind.

3. Name two ways of storing potential energy in bodies of matter. Give an example of each one.

4. Give an example of the use of electrical energy.

5. (*a*) How is radiant energy different from other forms of energy? (*b*) Name at least three varieties of radiant energy.

6. What is chemical energy? Give at least two examples of substances that have a great deal of chemical energy.

7. What form of energy is each of the following?

a) The energy in a hot brick lying on the ground

b) The energy in the spring of a watch when it has been wound up

c) Radio waves

d) The energy in an automobile "coasting" along a level street at twenty-five miles per hour

e) The energy in gunpowder

Problems to Solve

1. What form of energy does a common mouse-trap have when it is set?

2. What form of energy is there in the wax of a candle?

3. What form of energy do you use when you climb a stair? Explain your answer. What kind of energy has your body gained when you reach the top?

4. Reread "Looking Ahead to Unit 5" (pages 223-225) and tell what form or forms of energy are illustrated in each incident described.

5. Explain how a spring-board uses energy to help a diver.

6. What form of energy has a tank of compressed air? Explain.

7. When a lifted weight falls to the ground, what becomes of the stored energy?

8. Two weights, A and B, are suspended on ropes. Weight B has more potential energy than weight A. Give two ways that weight B can be different from weight A in order to have more energy stored in it.

Problem 4:

HOW DO WE CHANGE ONE FORM OF ENERGY INTO ANOTHER?

Did the long discussion of different kinds of energy puzzle you? Did it raise any questions in your mind? It puzzled some of the boys and girls in one science class, as the following conversation shows:

"Just about the time I think I can explain where to find one kind of energy, another kind pops up," said Alice, "and they get all tangled up in my mind."

"What were you thinking of when you got tangled up?" asked the teacher.

"Once I was thinking about a picture that fell off the wall at home. It made a terrible crash and broke itself all to pieces. I can see that whoever hung the picture put

potential energy into it. But when it hit the floor, it was going awfully fast. It must have had kinetic energy then."

Then Sara Jane spoke up. "I thought about the food I eat. You told us that food has chemical energy in it. And then you said it keeps us warm; that's heat energy. And it makes us move; that's kinetic energy. How do you explain that?"

"I don't blame you for being mixed up," answered the teacher. "The real trouble is that energy doesn't stay in one form all the time. It changes easily from one form to another. You can see better what I mean if we do some simple experiments."

Here are the experiments they did and some of the things they found out. Perhaps you would like to do the experiments yourself.

Experiment 32. *What Are Some Ways of Changing One Form of Energy into Another?* (*a*) Get a piece of lead at least as big as a five-cent piece, but not larger than a half dollar. Place it on a large piece of iron or a large rock and pound it vigorously with a hammer for a minute or two. Feel the piece of lead. What do you discover? What kind of energy did the moving hammer have? What kind of energy is produced in the lead?

b) Rub a coin rapidly on your sleeve. What form of energy did you use in moving the coin? What form of energy is produced in the coin?

c) Light a match. What form of energy does the wood of the match have? What two forms of energy are given out by the burning match?

d) Fill a test-tube half full of water. Cork it tightly enough so that steam cannot get past the cork. With a test-tube holder or a strip of folded paper hold the bottom of the tube in a flame so that the water is heated until it boils. Keep the cork

pointed away from yourself and everyone else. What happens? What kind of energy went from the flame into the water? What kind of energy did the cork get?

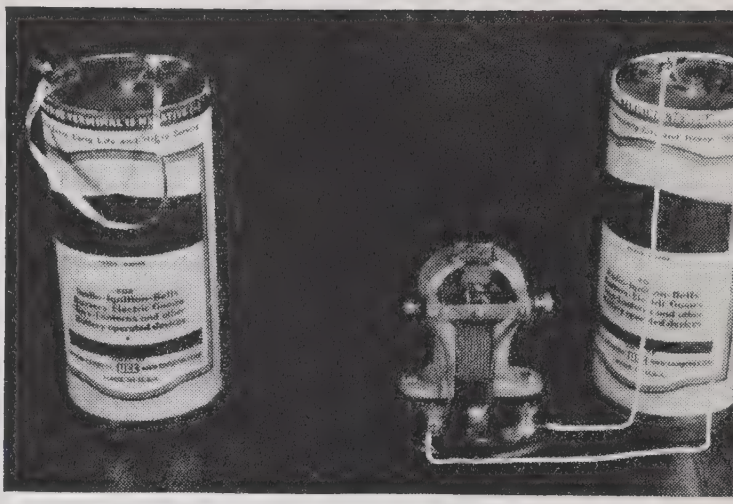


FIG. 192. Experiment 32*e* and *f*

e) Obtain an electric dry cell and a short piece of thin iron wire (or a strip of tin-foil about one-eighth of an inch wide). Attach the iron wire (or tin-foil) to the two binding posts of the cell for a short time. What happens? The materials of which the cell is made possess chemical energy. What form of energy comes out of the cell through the binding posts? What two other forms of energy appear in the wire?

f) Connect a dry cell to a small electric motor. What changes of energy take place?

In each part of the experiment you found that one form of energy was changed into some other form or forms of energy. Mechanical energy can be changed into heat energy. Heat energy can be changed into mechanical energy. Potential energy can be changed into kinetic energy. Chemical energy can be changed into electrical energy, which can be changed into kinetic energy. If the correct conditions are arranged, any kind of energy can be changed, or *transformed*, into another kind of energy. Many such changes are going on around us all the time.

A picture on the wall has potential energy that was given it by the person who hung it. As it falls, the potential energy changes into kinetic energy. When a bowstring is released, the potential energy of the bent bow changes quickly into the kinetic energy of the flying arrow. When food is used in your body, it is changed chemically by

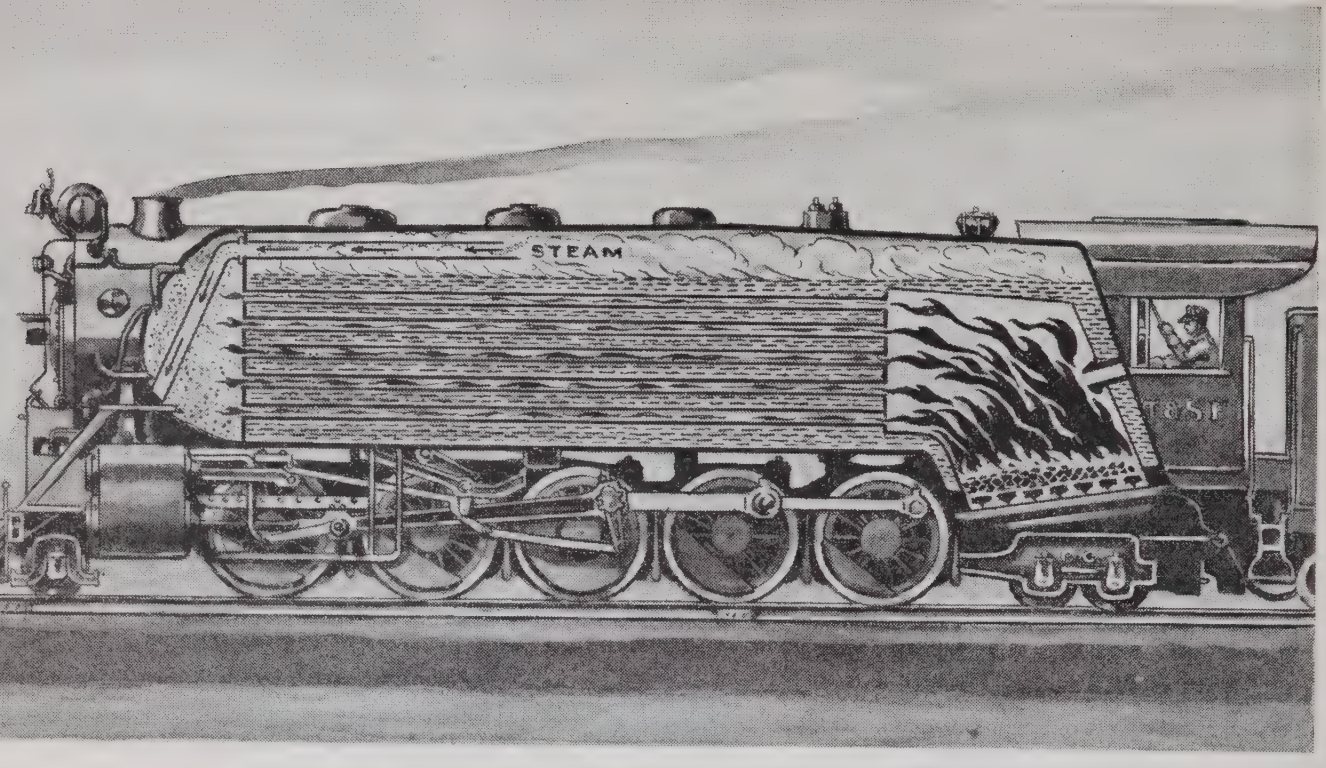


FIG. 193. This diagram of a locomotive will help you understand how the chemical energy in coal is changed to other forms of energy—heat, light, and the kinetic energy of the moving locomotive.

uniting with oxygen; its chemical energy changes into kinetic energy when we move and into heat energy that keeps us warm. Much of the radiant energy of the sun changes into heat energy when it strikes the earth. The burning of fuel in a fireplace changes chemical energy into heat. Some of the heat then changes into invisible radiant energy that radiates straight to you and changes back into heat when it strikes your skin and clothes.

In Experiment 32 the changes in the form of energy are easily seen. Now let us take something more complicated; for example, the energy transformations that take place in running a locomotive. At first the energy is stored as chemical energy in the coal. Then, when the coal is changed chemically by uniting with oxygen as it burns, the chemical energy changes into heat and light in the fire-box of the locomotive. The heat passes through the walls of the fire box into the water in the boiler. The water is changed into steam by the heat energy.

The rapidly moving molecules of the expanding steam strike against round pieces of steel, called pistons, in the

cylinders of the locomotive; the pistons move. In this way some of the heat of the steam is changed into the kinetic energy of the moving locomotive. This great machine must transform energy in order to do its work.

CAN ENERGY BE CREATED OR DESTROYED? For many years scientists have been studying transformations of energy. They have carried out many more complicated and more accurate experiments than you can imagine, and they have come to the conclusion that *energy is never made, nor is it ever destroyed.* Whenever one kind of energy appears, an equal amount of some other kind of energy disappears. Thus, when the hammer stopped moving in Experiment 32, its kinetic energy was gone, but a certain amount of heat energy appeared in the lead.

The fact that energy can be changed, but cannot be made or destroyed, is known as the *Law of Conservation of Energy.* This is one of the most important laws of nature ever discovered by scientists. They have learned about it only during the last one hundred years.

The Law of Conservation of Energy does not mean that all the energy we use is changed into the form we want and is used to do useful things. Inventors are constantly trying to increase the per cent of the chemical energy of coal that can be used in pulling a train. The best they have been able to do with a steam locomotive is to use about thirteen per cent of the chemical energy of the coal. The remainder is wasted. Some of it escapes in the form of heat in the smoke and steam that go out through the smoke-stack. Some escapes as heat in the air that is warmed by the sides of the locomotive. Some is sent out into space as radiant energy from the sides of the hot locomotive. Of all the electric energy sent into an

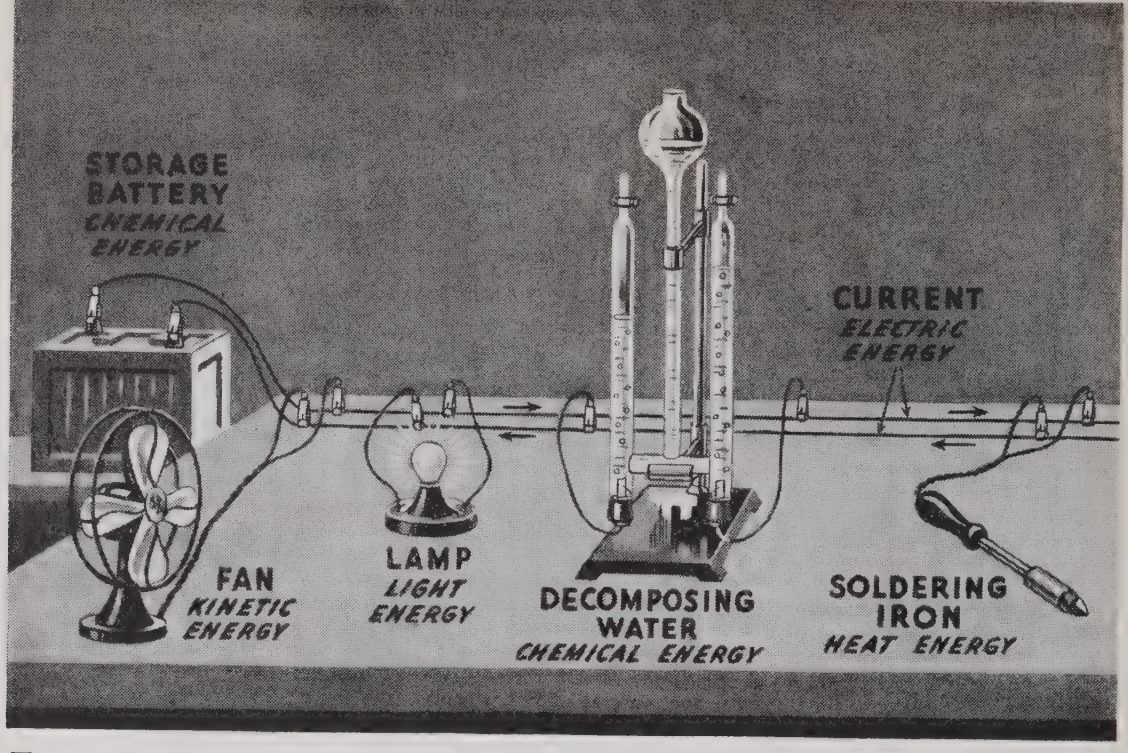


FIG. 194. Notice all the different forms of energy that come from the chemical energy of the battery. Electric energy comes first. This form of energy is changed into the kinetic energy of the moving fan, the light energy of the bulb, the heat energy of the soldering iron, and back again into chemical energy when it decomposes water into hydrogen and oxygen.

ordinary light bulb, less than three per cent is changed into light. More than ninety-seven per cent becomes heat that we do not want. Even so, the modern bulbs make nearly seven times as much light from a certain amount of electricity as the first bulbs did.

These ideas about the different kinds of energy and the way they change from one form to another without being lost may seem new and strange to you. However, they will be very useful in understanding what you see happening all around you. They will help you to understand the machines and devices of various kinds that help us to live, travel, and do our work more easily. In almost every unit of your science study from now on you will need to use what you have learned about force, work, and energy.

Self-Testing Exercises

1. Make a list of the six different forms of energy that have been mentioned in this unit. After each one give at least two

instances of the change of that kind of energy into other kinds. It is not enough just to name another kind of energy. Tell when and where the change occurs and name any objects or machines connected with the changes; thus: *In our bodies some of the chemical energy in our food changes to heat.*

2. What does the Law of Conservation of Energy mean to you?

3. Explain why the transformation of energy is important to you. Show that it helps you outside your science class.

Problems to Solve

1. What change or changes of energy take place as you wind a grandfather's clock and as the clock runs? See page 223.

2. What changes of energy were connected with the breaking of the concrete pavement described on page 224?

3. Why will a machine always stop if it is not supplied with energy from the outside?

4. We sometimes burn a candle to cause an energy change to take place. What is the change that we want? In what form is most of the energy wasted?

5. The wheel bearing of a railroad car sometimes gets so hot that it sets the cotton packing afire. This is what a railroad man calls a "hot box." What energy change causes this?

6. Obtain a large magnifying-glass or reading glass. Focus the sunlight on some dry, half-rotten wood or fine dry grass in a small pan or can lid. What change in energy takes place?

7. What becomes of the energy in the gasoline used to run an automobile?

LOOKING BACK AT UNIT 5

1. In a paragraph of not more than one-half page, write down the most important ideas of this unit.

2. Give the meaning of the following terms:

inertia	*kinetic energy*	*adhesion*
friction	*potential energy*	*radiant energy*
cohesion	*transformation of energy*	*chemical energy*
energy	*conservation of energy*	*centrifugal force*

ADDITIONAL EXERCISES

1. List as many energy changes as you can that take place in an automobile.

2. Read in reference books about the different kinds of radiant energy: X-rays, ultra-violet rays, and infra-red rays.

3. Many people have tried to invent a machine that would run and do work without having energy put into it. Such a machine has been called a "perpetual-motion" machine. Read in reference books about "perpetual motion" and perpetual-motion machines. Can you explain why no successful machine of this kind has ever been made?

4. Compressed air possesses energy, as shown by the fact that it can burst an automobile tire. Which form of energy does compressed air have? When does it receive its energy?

5. Learn how scientists measure work. Then measure the amount of work you do in climbing a stair. You can get information about measuring energy in a ninth-grade science book, in a physics book, or in an encyclopedia.

6. Which forms of energy are needed to operate a radio receiving set? Try to find out what each different form does.

7. List the effects of the energy of the sun on the earth.

8. Make an energy survey of your community to answer these questions: What different kinds of energy are used? Which are most important?

9. Why does it take more power to run an automobile uphill than downhill?

10. Two automobiles, C and D, are moving down the street. Auto D has more kinetic energy than auto C. Give two ways in which auto D can be different from auto C in order to have more of the energy of motion.

11. Why is it possible to tighten the head of a hammer by striking the end of the handle with another hammer?

12. Explain why wet paper tears more easily than dry paper.

13. If two pieces of lead are pounded together, they will stick. Why does the pounding make them stick together?

FIG. 195. About 1000 years ago, this was the best men could do to heat their homes. A hole in the roof carried away the smoke, and much of the heat escaped with the smoke. There was no way to carry the heat from a fire in one part of the building to rooms in other parts. Men had not yet learned how to control heat for their uses. In this unit you will learn many of the things that scientists have discovered about heat.

UNIT SIX

UNIT 6

HOW DO WE CONTROL HEAT?

INTRODUCTORY EXERCISES

1. Does an electric fan "cool the air"? Explain.

2. What happens to the molecules in a piece of iron when the iron is heated?

*3. Why do we put kindling under heavy fuels instead of on top of them when we are starting a fire?

*4. Where does a liquid go when it evaporates?

*5. What do you mean when you say that a gas condenses?

*6. Can you really see steam? Explain.

7. Why do kitchen utensils, such as spoons, often have their handles covered with wood or hard rubber?

8. Suppose that you are heating a piece of wire. Does heat really move along the wire as the wire becomes warmed? Explain.

9. Why do you become warm when the sun is shining on you through window-panes, even though the panes remain cold?

10. Why do you feel warmer on a hot day when the air is humid than on a hot day when the air is dry?

11. Do 50 pounds of ice at 32° F. cool a refrigerator more than, less than, or the same amount as 50 pounds of water at 32° F.? Explain.

12. How is evaporation used in an electric refrigerator?

13. Tell briefly how a home can best be kept comfortable in both summer and winter.

14. How does a hot-water heating system carry heat from a fire in one room to another room fifty feet away?

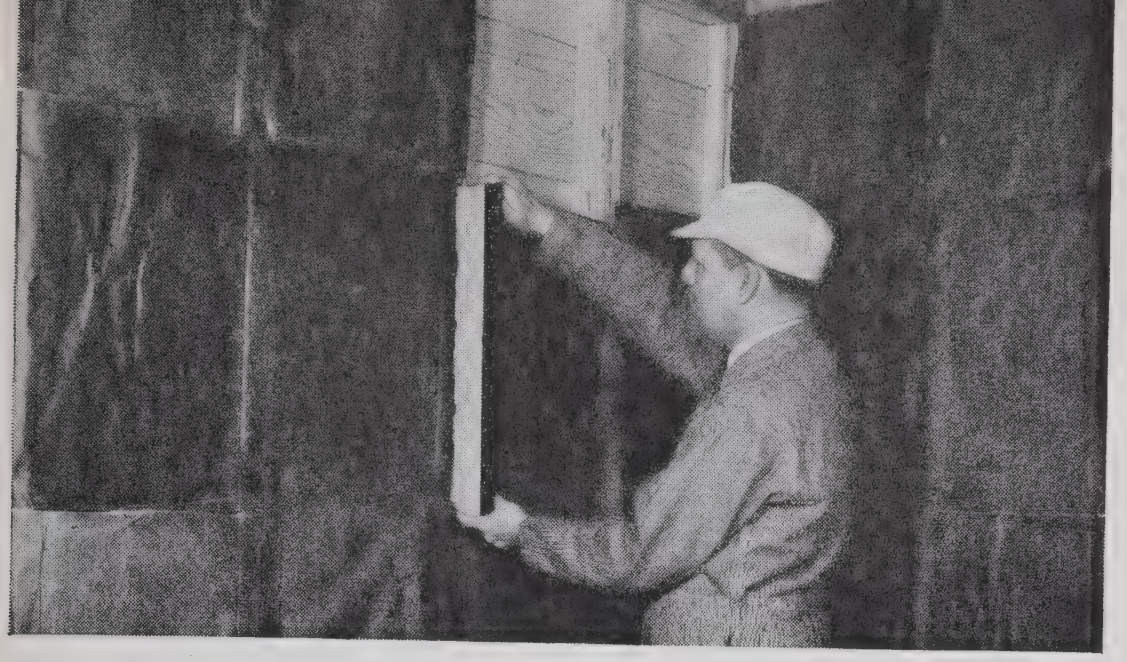


FIG. 196. Through his knowledge of heat control man has learned how to keep his buildings cool in summer and warm in winter. This workman is putting material in the walls of a house to *insulate* the house, that is, to keep heat from passing through the walls.

LOOKING AHEAD TO UNIT 6

GEORGE WAS trying to melt some lead in a metal spoon. He put the lead in the spoon and held it over a gas-burner. Soon the spoon became so hot that he had to drop it. His father saw what had happened and gave him a spoon with a wooden handle. "Here, George, use this spoon. Wood is a poor conductor of heat and will not let your hand get burned."

What did George's father mean when he said that wood is a poor conductor of heat? What is heat? How does heat move from one place to another? Why do we now have homes that are heated so much better than the homes of 200 years ago? How can electricity be used to remove heat from a refrigerator? Can you answer these questions?

Early people believed that heat was some kind of invisible liquid. They thought that this liquid moved from place to place in materials, much as water is soaked up by a sponge. When materials were heated, they soaked up a large amount of this invisible liquid. When a material became cold, in some way the liquid left it. This seemed

FIG. 197. Do you know what an "air-conditioned" building is? Perhaps you know that such a building is cool in summer no matter how hot the weather is. But do you know how it is kept cool? The science principles that you will learn in this unit will tell you.

like a good theory. It explained how things became heated and cooled, and why they expanded when they were heated and contracted when they were cooled. But some things about the way heat acts could not be explained by this theory; therefore scientists changed their ideas.

You have learned that heat is one of the kinds of energy. When materials are cold, they contain little heat energy; when they are hot, they contain much more heat energy. Heat makes materials expand, and it makes them change their state. Even though you have learned these things, you probably do not yet know just what heat energy is. What heat energy is will be one of the things to learn in this unit.

People's methods of heating their homes and other buildings have changed as much as their ideas about heat. Now most homes are so well heated that we scarcely know whether it is winter or summer unless we go outside. From your study of this unit you will be able to understand how we use heat in our homes. You will see how it is possible to transfer heat from a fire to the air in a room or to other

FIG. 198. In each picture heat is traveling in a different way. At the right the girl is warming her hands by holding them on warm metal. In the center a current of warm air is moving up from below. In the picture at the left *radiant energy* is traveling to the girl's hands, where it is changed into heat. This problem will explain these three different methods of heat transfer.

rooms far from the fire. You will also discover what happens to heat when a material changes from one state to another. When you understand this, you will see why a burn from steam is more painful than a burn from boiling water, how ice keeps things cool, and how it is possible to make ice with the aid of electricity.

Problem 1:

HOW DOES HEAT TRAVEL FROM ONE PLACE TO ANOTHER?

HOW DOES HEAT TRAVEL BY CONDUCTION? Without thinking, you have probably already realized the general rule that heat follows when it moves. Heat is always moving from places of higher temperature to places of lower temperature, or from warm places to cooler places. When you pick up a cold spoon, the spoon gets warmer, and your fingers feel cooler, because heat is moving from your fingers into the spoon. When you pick up a hot spoon, much heat moves into your fingers.

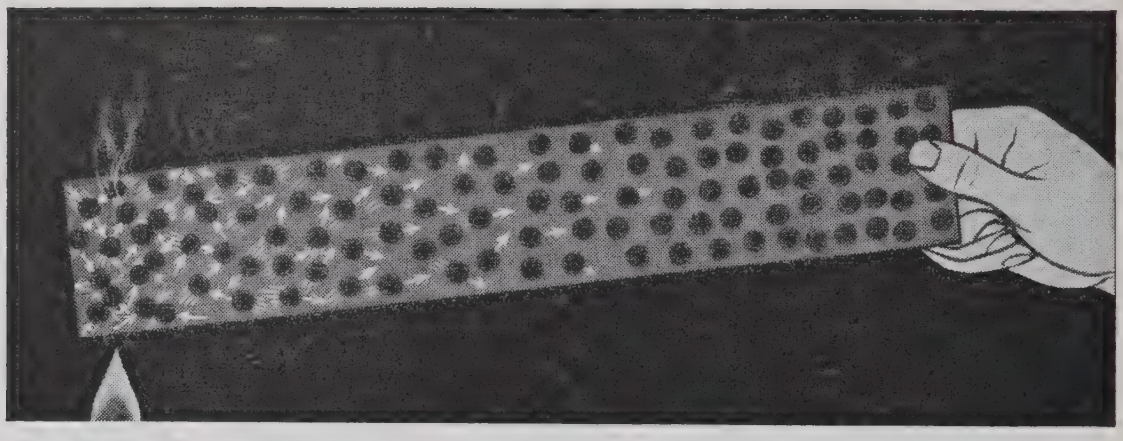


FIG. 199. This diagram will help you to understand how heat travels by conduction. After you have studied about conduction, a good test would be to explain exactly what this diagram shows.

When heat moves away from materials that are hot, or have a high temperature, it may travel in three different ways. These ways are *conduction*, *convection*, and *radiation*. They are called the three methods of *heat transfer*. To find out how heat travels, you will first do an experiment to get some facts about the conduction of heat. Then you will see how these facts can be explained.

EXPERIMENT 33. *How Is a Piece of Metal Heated?* With your fingers hold one end of a large nail in a flame for several minutes. What do you notice about the temperature of the nail? Does the nail become hot suddenly, or does it just get warmer and warmer? Rub your finger along the nail toward the flame. Where is the nail hottest? Coolest?

To explain how the heat traveled from the flame to the other end of the nail, you will need to know what is happening to the molecules in the metal. As you already know, the molecules of a substance are always moving. What happens to these molecules when a substance is heated? Scientists believe that when a substance is heated, its molecules move faster. When the molecules move faster, the temperature of the object rises. If metal feels cold, the molecules are moving slowly. If metal feels hot, the

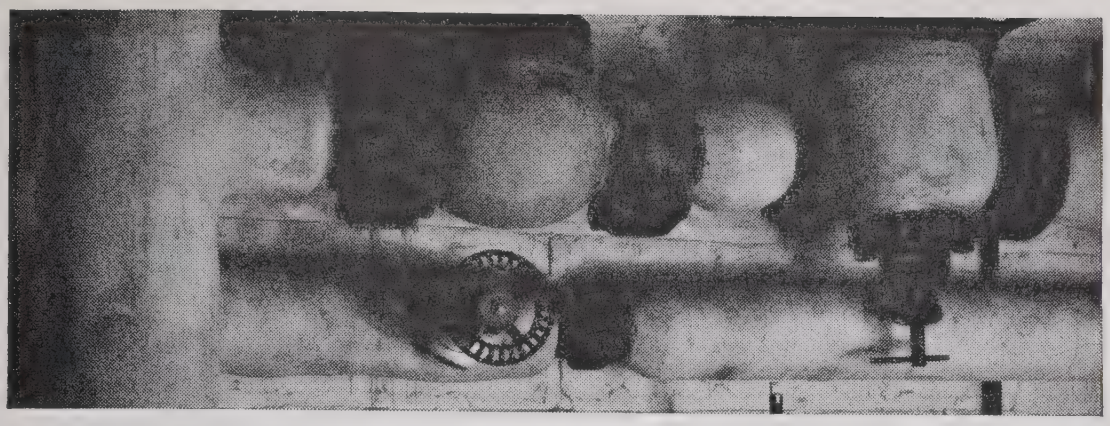


FIG. 200. These steam-pipes are covered with a layer of asbestos to prevent the escape of heat. Asbestos conducts heat very poorly.

molecules are moving rapidly. Whether an object is hot or cold depends upon how rapidly its molecules are moving.

Now to come back to the experiment. When the nail is held in the flame, the molecules in the part of the nail in the flame begin to bounce around faster. Since iron is a solid, the molecules cannot move very far before they bump into other molecules. When molecules get bumped, they start to move faster and bump the molecules next to them. In this way the molecules at the end of the nail in the flame start molecules moving faster all along the nail. When the molecules at the end in your hand begin to move faster, you feel the nail getting hotter.

This process of passing heat from one molecule to another is known as *conduction*. The word "conduct" means "to lead." It is a good word to describe this method of transferring heat, for heat seems to be led along as the rapidly moving molecules make their neighbors move.

The transfer of heat by conduction is very important. When you build a fire in the stove, the heat from the burning fuel is conducted through the metal walls of the stove to the air that is touching the stove. We make our cooking pans of metal so that the heat from the fire may

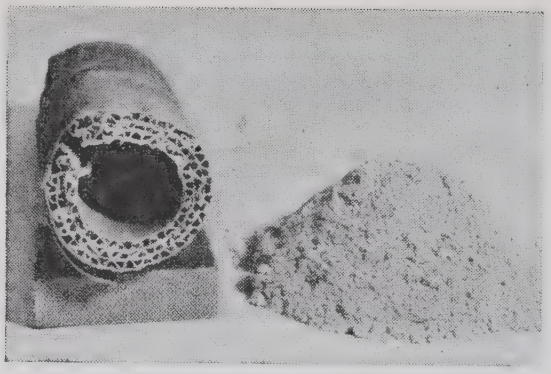


FIG 201. Asbestos materials used for insulation

be conducted to the food. All metals are good conductors of heat. This is one reason why metals are used in stoves, in radiators, and in cooking utensils.

For some purposes we want to stop the conduction of heat. You will be surprised to find how much we use poor conductors, or *non-conductors*, of heat. Handles of spoons used in cooking are often covered with wood, a poor conductor. When your mother places a hot dish on the table, she usually puts a napkin or other non-conducting material under it to keep it from ruining the varnish. Materials that conduct heat very slowly are called *insulators*.

Gases, such as air, are very poor conductors of heat. You know that you can hold your hand close to a very hot iron without being burned. If air were a good conductor of heat, you would be burned. Almost any material with air spaces in it is a good insulator. Notice the asbestos pipe covering in Figure 201. The asbestos itself is a good insulator. But, in addition, the covering is made with air spaces in it. At the right is a pile of ground-up asbestos. This is made into paste by moistening with water and is then put on pipes to insulate them, as in Figure 200.

You wear woolen and fur clothes in winter because they are poor conductors of heat. In addition, wool and fur have many spaces filled with air, an even poorer conductor. When you pile blankets on top of yourself on a cold winter night, the blankets do not give you heat. They are poor conductors; they keep the heat of your

body from escaping rapidly into the air of the room. Perhaps you have heard that a newspaper wrapped around you under a coat or placed between blankets will help you keep warm. Paper is a poor conductor of heat. In addition, the layers of paper hold air between them. The paper and the air together are good heat insulators.

Self-Testing Exercises

1. Explain how heat is conducted through a metal rod by telling what happens to the molecules when one end is heated.

2. How do we use materials that are good conductors of heat? Materials that are poor conductors of heat? Give examples.

Problems to Solve

1. Which of these are good conductors of heat: a bakelite cup, a pencil lead, a porcelain knob, an aluminum pan, a brick, an iron shovel? If you do not know, how can you find out?

2. To keep warm in the winter, we usually cover ourselves with a woolen blanket. But we may also cover a piece of ice with a blanket to keep it from melting in the summer. How does the blanket help us keep warm and help the ice keep cool?

3. If you were carrying ice-cream on a hot day, would it be better to use a tin bucket or a paper bucket? Why?

4. Birds ruffle up their feathers on cold days in order to keep warm. Explain how this helps.

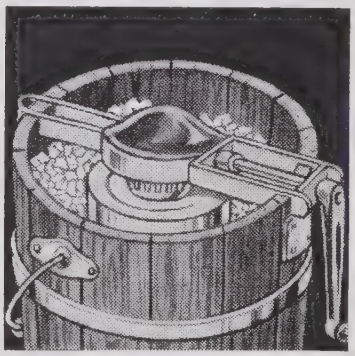


FIG. 202

5. The outer pail of an ice-cream freezer is usually made of wood, and the inner can is made of thin metal (Figure 202). Explain why different materials are used in the two cans.

6. Wrap a piece of paper tightly around an iron rod. Hold the rod in the flame for a short time. Does the paper burn? Wrap the paper around a wooden rod and hold it in the flame for the same time. Explain the difference in what happens.

HOW DOES HEAT TRAVEL BY CONVECTION? Did you ever come into the house on a cold winter day and stand over the register of a hot-air heating system? If you have had this experience, you know that a current of air was bringing heat from the furnace to you. From your study of Unit 4, you know that the current of air from the furnace was a convection current. Also from your study of Unit 4 you will remember that gravity made the warm air move up from the furnace (page 216).

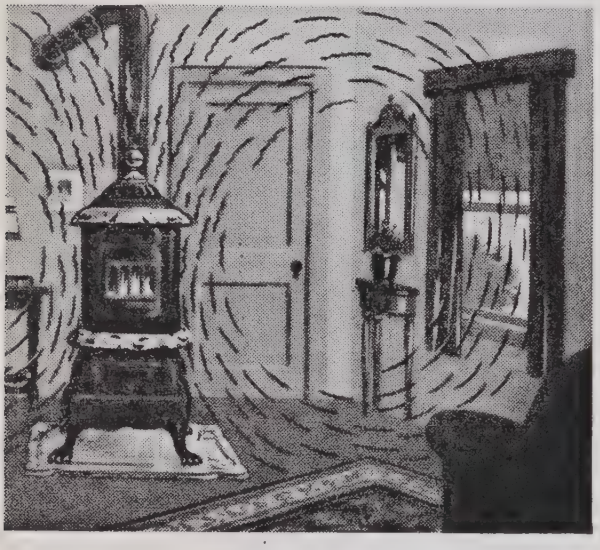


FIG. 203. Air currents set up by a hot stove

Transfer of heat by *convection* is quite different from transfer of heat by conduction. When heat is conducted, it passes from molecule to molecule. When it is transferred by convection, the molecules of heated gas or liquid actually move from one place to another. For example, the molecules of air heated in the furnace move from the basement up into the rooms, taking heat with them. When the molecules strike the furniture, walls, or objects in the room, they make the molecules that compose these objects move faster. In this way the molecules of heated air pass on some of their heat to the molecules they strike, and warm the objects in the room by conduction.

Let us take another example of the transfer of heat by a convection current and see how it works. Suppose you have a stove in the center of a large room. All the windows and doors are closed, and you build a fire in the stove. By conduction the heat from the fire passes through the iron walls of the stove and into the air that touches the iron. The air around the stove expands when it is heated. The

cold air near the windows weighs more than the air around the stove; therefore this cooler, heavier air sinks to the floor, forcing the air around the stove toward the ceiling.

The stove keeps the air around it warmer than the air in the other parts of the room; so the convection current continues. In this way the heat from the stove is transferred to all parts of the room by the moving air. When heat is transferred by the movement of heated air, or any other fluid, the heat is transferred by convection.

Self-Testing Exercises

1. A person is sitting at a window on the side of a room farthest from a stove. How does the heat from the stove warm him? Make a diagram to illustrate your answer.

2. Is the air of a heated room warmer near the ceiling or near the floor? Why?

Problems to Solve

1. John's science teacher told him that he could hold the bottom end of a long test-tube in his hand while he heated the water at the top of the test-tube to the boiling point, but that he could not hold the top end of the test-tube in his hand while he heated the bottom. Is this true? Why?

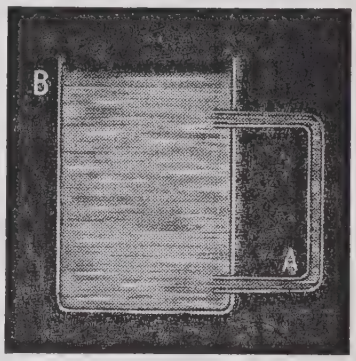


FIG. 204

2. Hot-air and hot-water furnaces are always placed in the basement or on the first floor, never on top floors. Why?

3. If you wanted to get much air from the outdoors into a heated room in the winter, how would you arrange the openings in the windows?

4. A tank of cold water and a pipe were arranged as shown in Figure 204. A fire was started around the pipe at A. Soon the tank felt warm at point B. Tell how the heat reached that point from the fire. Be sure to name the method of transfer that took place in each step.

HOW IS HEAT TRANSFERRED BY RADIATION? The third method of heat transfer is quite different from either conduction or convection. In both conduction and convection heat is transferred by the moving molecules of some material. But, strange as it may seem, heat has a way of traveling where there are no molecules. You can see that the transfer of heat from the sun to the earth cannot be explained by either conduction or convection. The air extends only about 100 miles above the earth. The remaining distance of over 90,000,000 miles is empty space.

In empty space, where there is no material, there can be no molecules. You know, however, that we do receive heat from the sun. How can you explain this? Scientists tell us that the heat is transferred from the sun to the earth in the form of *radiant energy;* that is, by *radiation.* (See page 247.) An experiment will help you to see how this takes place.

EXPERIMENT 34. *How Is Heat Transferred by Radiation?* Heat an electric radiator (like the one shown in Figure 198, page 261) or a toaster until it glows. If you do not have either of these, a lighted candle may be used. Hold your hand at the side of the flame or source of heat, about six inches from it. Can you feel the heat? The heat that you feel is not coming to you by conduction, because you are not touching the object. It is not reaching you by convection, because a warm current of air is not flowing from the source of heat to your hand. (This may be tested with smoking incense or cork.)

No one knows exactly how radiation takes place. You can, however, get a general idea of what happens in radiation. A hot object gives out radiant energy. This energy is invisible, and it is sometimes called *radiant heat.* As an object becomes hotter and hotter, it gives out more and more radiant energy. This energy travels in straight lines

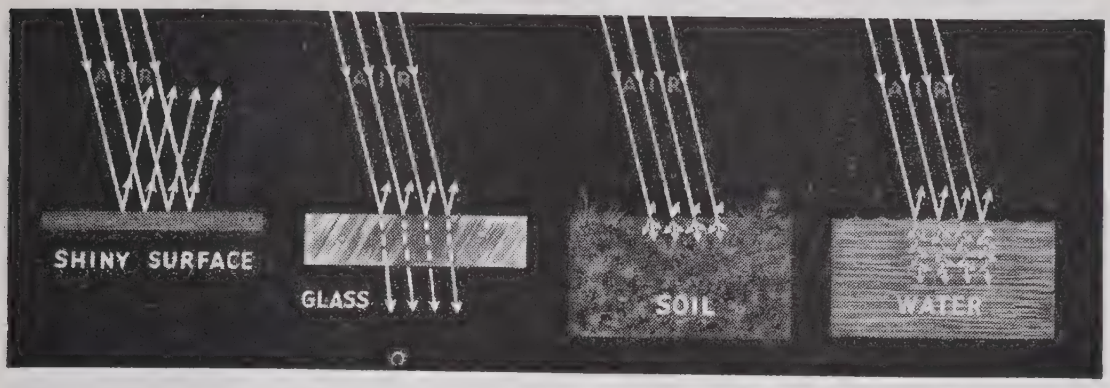


FIG. 205. In general, dark-colored materials *absorb* much radiant energy. Light-colored and "shiny" surfaces *reflect* the radiant energy without changing it to heat; therefore they are warmed very little when radiant energy strikes them. Many substances, like glass and air, that allow light to pass through them, also allow radiant heat to pass through them without absorbing much of it.

through space, but this radiant energy or radiant heat is not true heat. You can see that if it were, the air high above the earth would be warm, because it is nearer the sun than the lower air. But, as you know, the tops of high mountains are cold, and aviators must wear heavy clothing if they go very high.

But this radiant energy that travels through space can be changed to heat energy. When radiant energy strikes materials that can absorb it, it sets the molecules of the material in more rapid motion. Thus the radiant energy is changed into heat energy. An experiment will help to make this clearer.

EXPERIMENT 35. *How Is Radiant Energy Changed to Heat?* Take two test-tubes and partly cover one of them with smoke by rotating it in a candle flame. Place the two tubes in an upright position and nearly fill the tubes with water. Take the temperature of the water in each tube and record the readings. Now bring the tubes into the direct sunlight and leave them there for fifteen minutes. Again take the temperature of the water and record the readings. What do the results show?

In a clear test-tube the temperature of the water rises much less than in a blackened tube. This happens because the blackened tube absorbs a great deal of radiant energy and changes it to heat. The clear tube absorbs less of the radiant energy than the black tube. Study Figure 205 carefully, and read what is said below it.

Now you can see why the air is not warmed very much by the sun. The air absorbs very little of the radiant energy; therefore very little of it is changed to heat by the air. You can also see why you are warmed if you stand in front of a sunny window on a cold day. The window glass lets the radiant energy pass through without absorbing it. If you touch the window-pane, you find that it is cold. When the radiant energy passes through the glass and strikes your face or clothes, it is absorbed and changed to heat energy. Then you get warmer.

You can now understand why transfer of heat by radiation is different from transfer of heat by conduction and convection. No molecules are needed to transfer the heat. Energy is transferred from the fire or sun or stove by the radiant energy that they send out. This energy passes through transparent materials, such as air and glass, without warming them. But when the radiant energy is absorbed by some material and is changed into heat energy, then it sets the molecules of the material moving faster, and the material gets warmer.

Self-Testing Exercises

1. Tell in your own words how you are warmed when you stand in front of an open fire.

2. What is wrong with this statement? *Radiation is heat.* Change the statement to make it correct.

3. How is the transfer of heat by radiation different from conduction and convection?

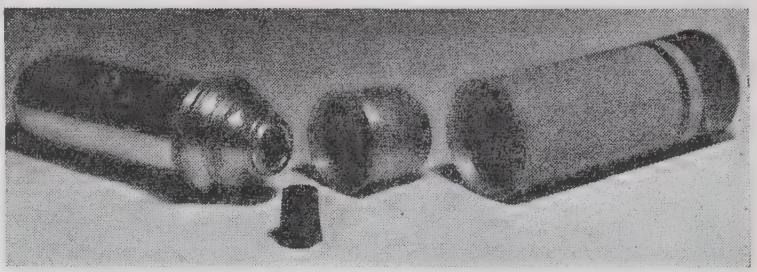


FIG. 206. The glass bottle, shown at the left, has double walls, the space between the walls being a partial vacuum.

Problems to Solve

1. Give three original examples (ones that are not given in a book, but ones that you have observed) of objects being warmed by conduction, three examples of heat transferred by conduction, and three examples of objects being warmed by radiation.

2. Is this statement true? *Radiant energy from the sun passes through the space between the earth's atmosphere and the sun without warming the space.* Explain why you believe that your answer is correct.

3. Can a red-hot stove heat materials by conduction, convection, and radiation? Explain.

4. On a sunny day snow melts faster where it is dirty or under dead leaves than where it is clean or in the open? Explain.

5. In hot countries the people wear white clothes. Why are these cooler than dark clothes?

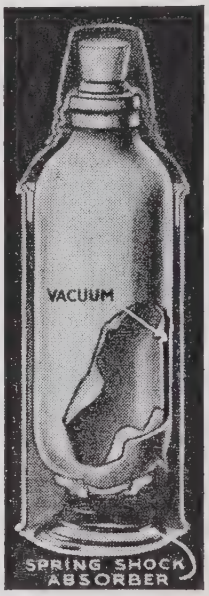


FIG. 207

6. Figures 206 and 207 show how a vacuum bottle is constructed. Such a bottle keeps hot coffee too hot to drink for several hours. It also keeps cold things cold just as well.

a) How does the vacuum between the two glass walls help keep the coffee hot?

b) How could heat get across the vacuum? In a reference book find how that method of heat transfer is prevented.

c) Why is a cork instead of a metal stopper used?

d) Why will the bottle keep things cold as well as hot?

7. Plan and carry out an experiment to find how rapidly hot water loses heat in a vacuum bottle.

FIG. 208. Scenes like this are common in cities during the hot summer weather. The cool water is a relief from the heat, and so long as it continues to evaporate from the children's bodies, it keeps them cool. Do you know why evaporating liquids keep things cool?

Problem 2:

WHAT HAPPENS TO HEAT WHEN A MATERIAL CHANGES FROM ONE STATE TO ANOTHER?

IF YOU HAPPEN to live, or ever have lived on a farm, you may have seen your father do a curious thing. You may have seen him place a tub of water in the cellar to keep the vegetables stored there from freezing on a cold night. The curious part about this is that when the water in the tub freezes, it keeps the air in the cellar warm. Do you know how water keeps objects around it warmer while it is freezing?

When you go swimming on a hot, sunny day, you have probably noticed that if you sit on the beach, you get very hot. But if you go into the water and get your skin and bathing suit wet, you can sit in the hot sun and feel quite cool until your skin and bathing suit dry. The sun is just as hot as it was before you got yourself wet, but you feel cooler. Why?

A certain thing is true about each example in the two paragraphs above. In each case a change of state takes place. When water freezes, it changes from a liquid to a solid. When ice melts, it changes from a solid to a liquid. When your bathing suit dries, the liquid water changes to a gas. To explain these examples and many others you

FIG. 209. The ice melts, and the milk keeps cool in the cans. Why does the ice take heat away from the milk, the cans, and the air when it changes to water?

will have to discover what happens to heat when a material changes from one state to another.

WHY DOES ICE COOL THINGS WHEN IT MELTS? On a hot summer day we often put some ice in a glass or a pitcher to make ice-water. When the ice is added, some of it melts, and the water is cooled until it is at about the freezing temperature. If you place the pitcher in the sun, the water still remains at about the same temperature until all the ice is gone. Now you know that the radiant energy from sun is giving heat to the pitcher of water, yet the water does not get any hotter until all the ice is melted. Why is this true?

EXPERIMENT 36. *What Happens When a Mixture of Ice and Water Is Heated?* Fill a beaker two-thirds full of crushed ice. Place the beaker over a wire gauze on a ring stand. Heat the beaker with a low flame. Stir the contents of the beaker constantly and take the temperature of the water from time to time until the ice is all melted. Does the water get hotter and hotter, or does it stay cold until all of the ice is melted?

Experiment 36 gives you something to think about. Ordinarily when you heat water, it gets hotter. In this case the water did not get much hotter when it was heated until after all of the ice was melted. This raises an interesting question: What became of the heat before the water

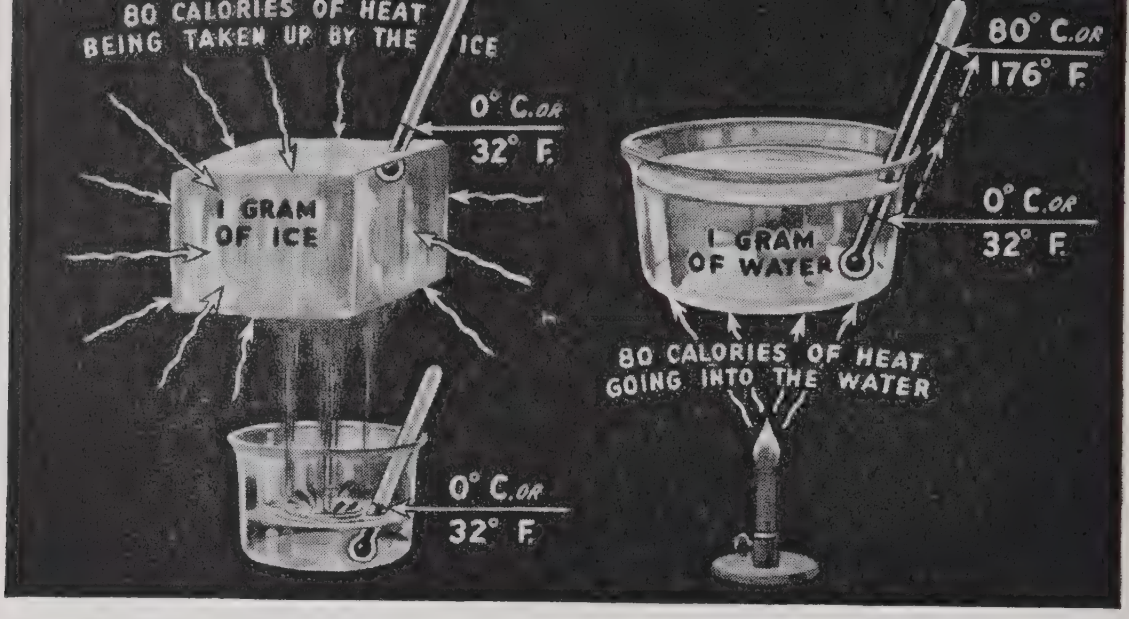


FIG. 210. Scientists measure heat in *calories*. A calorie is the amount of heat required to raise the temperature of one gram of water one degree centigrade. Careful experiments show that it takes about 80 calories of heat to melt one gram of ice, and the water to which the ice changes stays at the same temperature as the ice. But when you put 80 calories of heat into the gram of water, the water gets so hot that it will burn your hand.

began to get warmer? The only satisfactory explanation is that the heat was being used to change the ice into water without warming the water at all.

Experiment 36 is a good example to show that heat is really a form of energy. Energy is what makes things happen, makes changes take place. Usually heat seems to warm things. In this experiment heat changes ice to water without warming it. Study Figure 210 carefully.

Now we will try to explain what happens when ice melts. The water molecules, of which the ice is made, are held tightly together—so tightly that they cannot slide around over each other. In order to pull these molecules apart so that they can move more freely, as they do in liquid water, some work must be done. You know that energy is needed to do work. The energy needed was supplied by the heat of the flame. The heat energy from the flame was used to pull the molecules of ice apart instead of to make the molecules of water move faster. That is why the temperature of the ice-water did not get higher. After the ice was

melted, the heat energy from the flame was used to raise the temperature of the water, that is, to make the molecules move more rapidly.

Now you can see why adding ice to water cools it so much. When ice is added to water, the heat required to melt the ice comes from the water. Ice is a good cooling material, and it melts slowly because so much heat has to go into it to change it to water. Therefore it takes a great amount of heat away from objects that are near it.

What you have learned about melting ice is true of other solids. Whenever a solid is changed to a liquid, heat energy is used in pulling the molecules away from each other. However, the amount of heat needed to melt solids is not the same for all kinds of solids. For example, the amount of heat required to melt a gram of paraffin is different from that required to melt one gram of ice. But ice uses up more heat in melting than does almost any other solid substance; therefore it is a good "cooler."

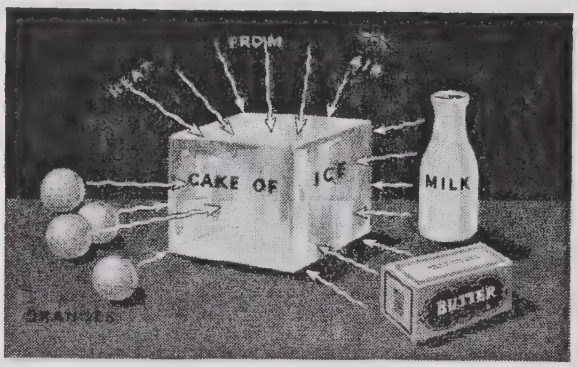


FIG. 211. Ice cools objects because heat passes from the warm objects to the cold ice.

Self-Testing Exercises

1. Explain why ice is a good material to cool liquids.
2. What work is heat energy doing while ice is melting?
3. Why will a pound of ice cool a pitcher of water more than a pound of ice-water will cool the water in the pitcher? Keep in mind that both the ice and ice-water are at 32° F. or 0°C.

Problems to Solve

1. We use ice in refrigerators to keep our food cool. Some people cover the ice with blankets or paper to keep it from

melting. Will this keep the food as cool as it would if the ice were allowed to melt? Explain.

2. Near a large body of water in which ice is melting the temperature of the air is cooler than it is at a place one hundred miles inland from the body of water. Explain.

3. Plan an experiment to show that a pound of ice will cool water more than a pound of ice-water.

4. Why do snow and ice melt slowly in the spring?

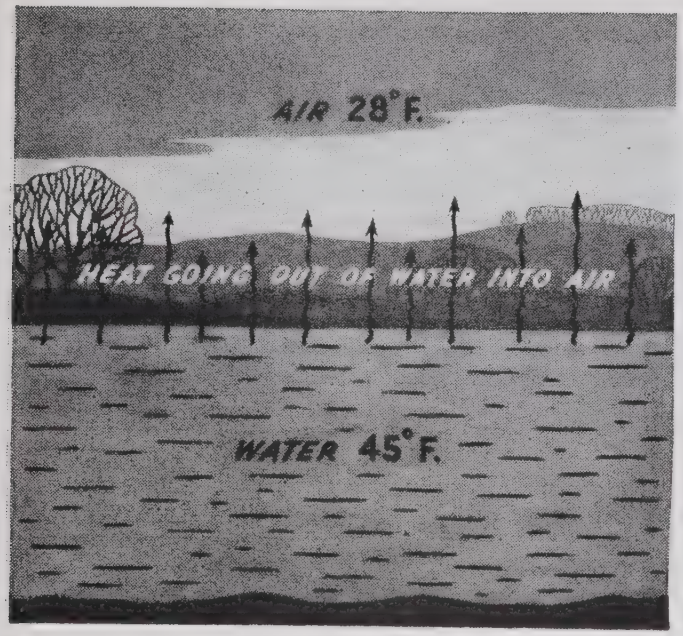
WHY DOES FREEZING WATER KEEP THE AIR AROUND IT WARM? You have already learned that farmers use freezing water to keep vegetables from freezing. Florists also use freezing water to keep flowers from freezing when they are sent by airplane. Airplanes fly at such high altitudes that the temperature of the air is often below freezing. At these temperatures the flowers would be ruined.

Nobody knew what to do to protect the flowers until a scientist suggested that the florists wrap the boxes in many thicknesses of wet newspapers. This strange plan was tried, and it kept the flowers from freezing. Can you explain why?

EXPERIMENT 37. *Does Water Keep Getting Colder While It Is Freezing?* Fill a test-tube or small bottle two-thirds full of water. Take its temperature. Put the test-tube into a can or pail and pack a mixture of finely cracked ice and common salt around it. Put a thermometer in the test-tube and take the temperature of the water every half minute until it is several degrees below freezing. (Do not try to remove the thermometer until the ice in the tube has melted.)

Time	*Temperature*
Start	70°F.
$\frac{1}{2}$ minute	67°F.
1 minute	63°F.
Etc.	

Make a careful record of the time and the temperature, as shown at the right. Also make a graph to show the rate at which the water cooled. What does your graph show?



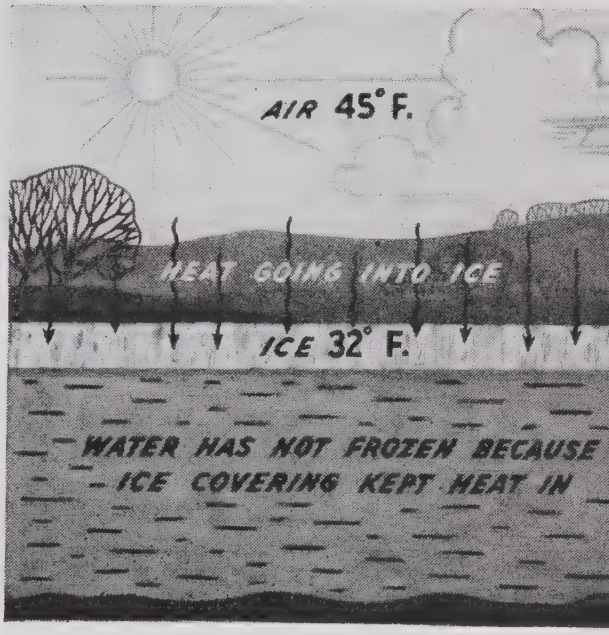


FIG. 212. These two pictures will help you understand what happens to heat when water freezes and when ice melts.

We take heat out of water by having it touch colder things. When we do this, the temperature of the water goes down steadily until it reaches the freezing point. Then, as you found in Experiment 37, the temperature stays the same until all the water has frozen. After that the temperature begins to fall again.

Why does the water stay at the freezing point so long? You know that heat is being taken out of it all the time, yet it gets no colder. All of the heat that comes out of the water while it is freezing must come out to let the water change from liquid to solid. While the last of this heat is coming out, the water remains at 32° F. Thus, whenever water freezes, it gives out a great amount of heat. The heat that was put into the water to melt it must be taken out again to freeze it.

Can you tell now why flowers shipped by air do not freeze when they are wrapped in wet newspapers? The flowers will not freeze until they are cooled to about 30° F. Even though the temperature around the box falls

very low, the water freezes first. As it freezes it gives out heat, and this heat keeps the flowers from getting too cold. The same thing happens when a tub of water is placed in the cellar. As the water freezes, it gives out heat to the air; therefore the air in the cellar does not fall below freezing, and the vegetables do not freeze.

Self-Testing Exercises

1. Why does water remain at the freezing point until it has all frozen?
2. How does freezing water keep the air in a cellar warmer than the air outdoors on a very cold night?
3. Why does ice form slowly rather than rapidly in the ice trays of an electric refrigerator?

WHAT HAPPENS TO HEAT WHEN A LIQUID CHANGES TO A GAS? If you place a drop of alcohol or ether on your hand and let it evaporate, a curious thing happens. The spot on your hand from which the liquid is evaporating gets cold. Now you know that when anything gets cold, heat is being taken away from it. Apparently, heat is taken from your hand when the ether evaporates. Let us try an experiment to see if this guess is true.

EXPERIMENT 38. *Does an Evaporating Liquid Take Heat from the Things around It?* (*a*) Let a stoppered bottle of ether, alcohol, or water stand in your room for several hours so that it will be at room temperature. Get a one-holed stopper that will fit the bottle and push a chemical thermometer through the hole. Tie a piece of thin cloth or a thin layer of cotton about the bulb of the thermometer. Remove the regular stopper from the bottle and put the stopper and thermometer into the bottle so that the bulb is in the liquid. Have the stopper fit tightly.

After a few minutes read the thermometer. With another thermometer take the temperature of the air in the room. How do the two temperatures compare?

FIG. 213. Apparatus for Experiment 38

b) Without removing the stopper from the bottle, slide the thermometer upward so that the bulb is above the liquid. After a few minutes read the thermometer. Is there any change in the temperature? Is the liquid on the bulb of the thermometer evaporating?

c) Now remove the thermometer and stopper from the bottle and hang them up. Watch the mercury in the thermometer. How low does it go? Is the liquid evaporating?

d) If you are using water, fan the thermometer. What effect does this have upon the temperature?

e) If possible, repeat the experiment with one of the other liquids named in the directions and compare the results. Explain any differences you find.

Your experiment showed you that so long as the thermometer was inside the bottle, where no evaporation could take place, the temperature remained the same as that of the room. As soon as the thermometer was brought into the air, the temperature dropped. When the thermometer was fanned, the temperature dropped still further.

What happened in your experiment is somewhat similar to what happens when a solid changes to a liquid. Heat is required to change a solid to a liquid. Heat is also required to make the liquid change to a gas. The heat comes from

the things around the evaporating liquid. When a drop of water or of alcohol evaporates from your hand, heat is taken from your hand. When water evaporated from the thermometer, heat was taken from the mercury in the thermometer. Fanning the thermometer caused the water to evaporate faster. Heat was taken more rapidly from the mercury, and there was a greater cooling effect. If alcohol or ether is used, the cooling effect is much greater than with water because alcohol and ether evaporate very much more rapidly than water.

Now you can see how evaporation causes cooling. If evaporation is slow, there is little cooling. If it is rapid, a great deal of cooling may take place. With ether and other liquids the temperature may even go below the freezing temperature of water.

Cooling by evaporation is very important in keeping our bodies cool in summer. Our bodies are constantly making heat. We must get rid of some of the heat, or the temperature in our bodies will go above 98.6° F., the best temperature for health. Our bodies are provided with *sweat glands*. When the weather is warm, these glands pour a great deal of water (sweat, or *perspiration*) on our skins. As the water evaporates, we are cooled. On hot days when the air is at the same temperature as our bodies, or even warmer, we could not keep cool without evaporation of sweat from our skins.

The cooling effect of evaporation is used to tell how much moisture there is in the air. The instrument used is called a *wet-and-dry-bulb thermometer*. It usually consists of two thermometers. One thermometer has nothing around the bulb and is used to take the real temperature of the air. The bulb of another thermometer has a piece of cloth around it. This cloth is either dipped in water

when a reading is to be taken or is kept wet by having the lower end of the cloth in a small bottle of water.

The amount of moisture in the air is called the *humidity*. The humidity of the air can be measured by a wet-and-dry bulb thermometer because evaporation is more rapid when the air is dry. When the evaporation is more rapid, the wet-bulb thermometer is cooled more. If the air is quite moist, there will be little evaporation, and the wet-bulb thermometer will read almost the same as the dry-bulb. When the air becomes completely full of water vapor, evaporation of water stops. Then the two thermometers read the same.

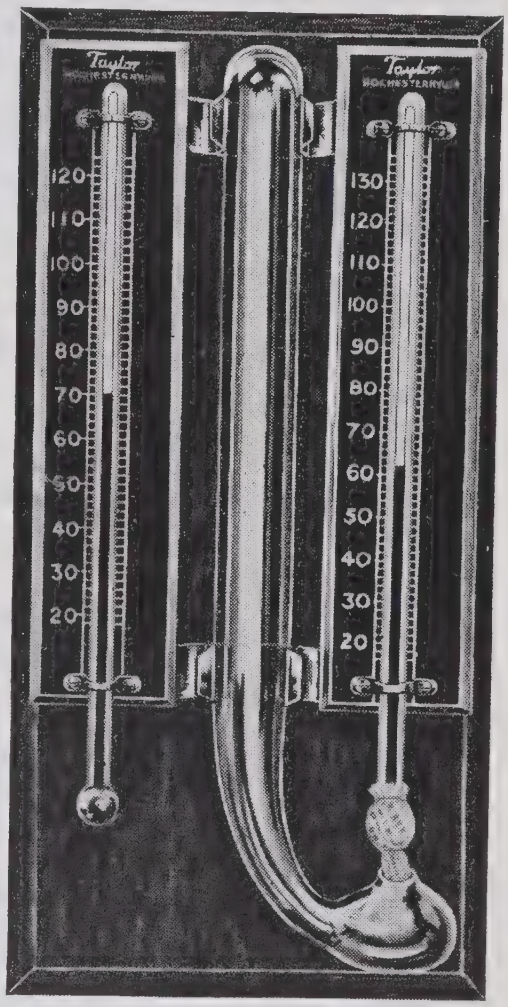


FIG. 214. A wet-and-dry-bulb thermometer

Evaporation takes place at all temperatures, but as a liquid becomes hotter, it evaporates more rapidly. When it is heated enough, it boils; that is, bubbles of hot vapor form in the liquid and rise to the top. Water, as you know, boils at 212°F. or 100° C. When water is first heated, the temperature continues to rise until it reaches the boiling temperature. Then steam begins to form very rapidly. After steam has begun to form, the temperature of pure water goes no higher, no matter how hot the fire is or how long you boil the water.

What do you suppose happens to this heat? It is used in changing the water into steam. It makes the molecules pull loose from each other and fly farther apart. The molecules fly so far apart that a cubic foot of water makes 1600 cubic feet of steam. The heat energy from the fire does the work necessary to bring about this change from liquid to gas.

Self-Testing Exercises

1. Why does a wet-bulb thermometer usually show a lower temperature than a dry-bulb thermometer?

2. How wet is air when a wet thermometer and a dry one show the same temperature? How do you know?

3. Why is perspiration very useful to us during hot weather?

4. A boy went in swimming on a warm summer day when the air and the water were both the same temperature. He shivered whenever he got out of the water. Explain why.

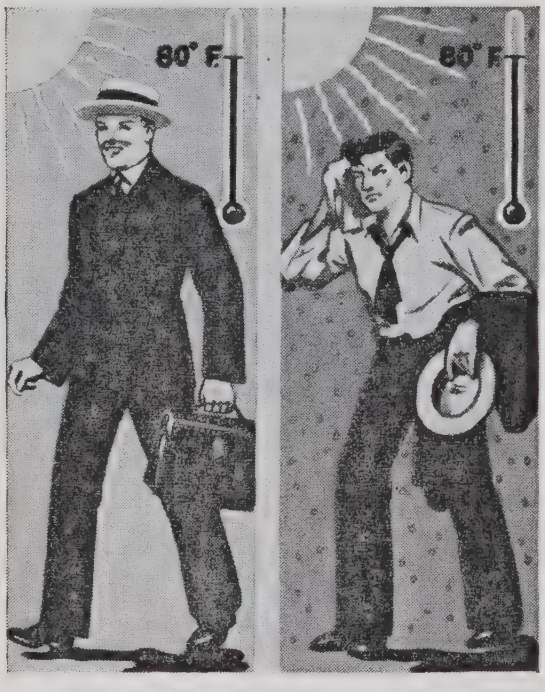


FIG. 215. In the picture at the left the air is clear and dry. At the right the air is very humid. Explain the pictures.

5. If you draw your breath quickly through your partly opened mouth, your tongue feels cool. Why is this?

Problems to Solve

1. Will fanning cool a person on a day when the thermometer stands at 99° F. and the air is already full of water vapor?

2. In some hot, dry countries the drinking water is kept in the shade in porous bags or in porous earthenware jars. Enough water seeps through these bags and jars to keep the outside surface slightly moist. Will the water inside be warm or cool? Why?

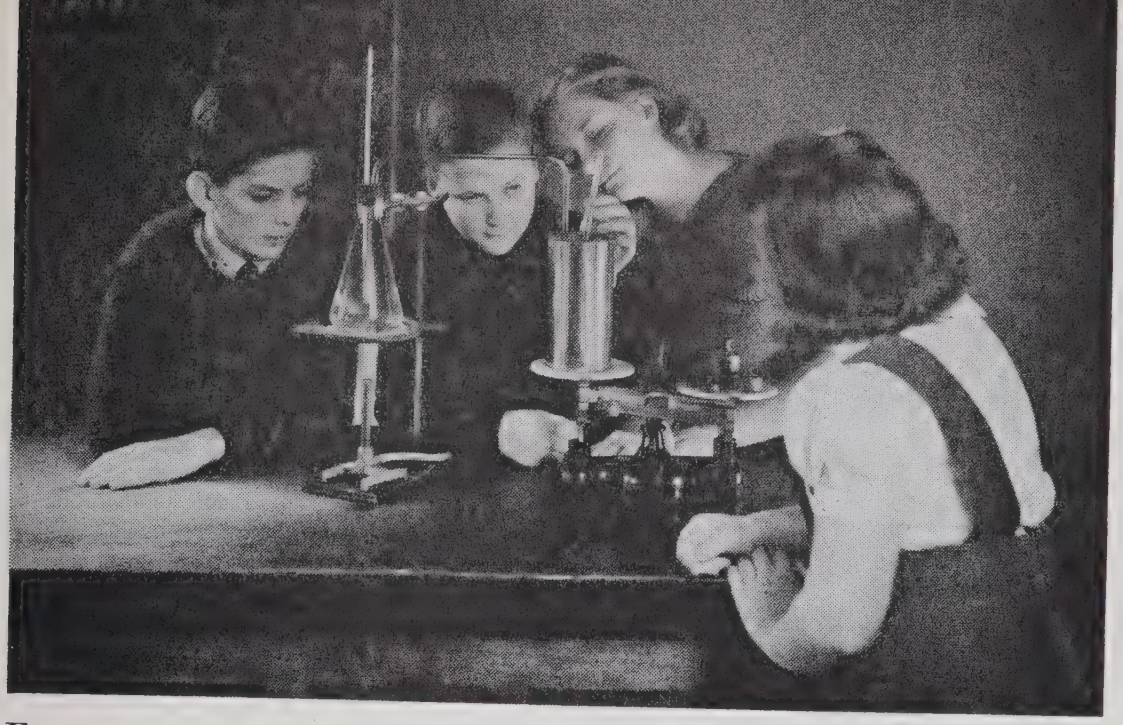


FIG. 216. Apparatus for Experiment 39

3. Some days in summer seem very warm, and our skins are kept wet with perspiration even though the thermometer says it is no warmer than other days when we are quite comfortable. Why do we feel so differently (Figure 215)?

4. Explain why a fan makes us more comfortable on a day when the temperature is 100° F.

5. Dry ice (solid carbon dioxide) is a solid that evaporates without melting. As it evaporates, it keeps itself at a temperature of about −109° F. until it is gone. Why does it stay so cold?

6. After water has begun to boil, will potatoes cook more quickly with a high fire than with a low fire? Explain.

WHAT HAPPENS WHEN VAPOR CONDENSES? Your mother has probably told you that a burn from steam is worse than a burn from boiling water. Can this be possible? If so, why? The following experiment will help you to answer the questions.

EXPERIMENT 39. *Which Can Warm Things More, Boiling Water or Steam?* (*a*) Place a can containing at least 300 cubic centimeters of cool water on the left side of a pair of balances. Balance the can and the water. Then add 30 grams in weight to the right side. Take the temperature of the water. Take the temperature of the steam in a flask above some boiling water. Pass live steam from the flask through a tube into the can of

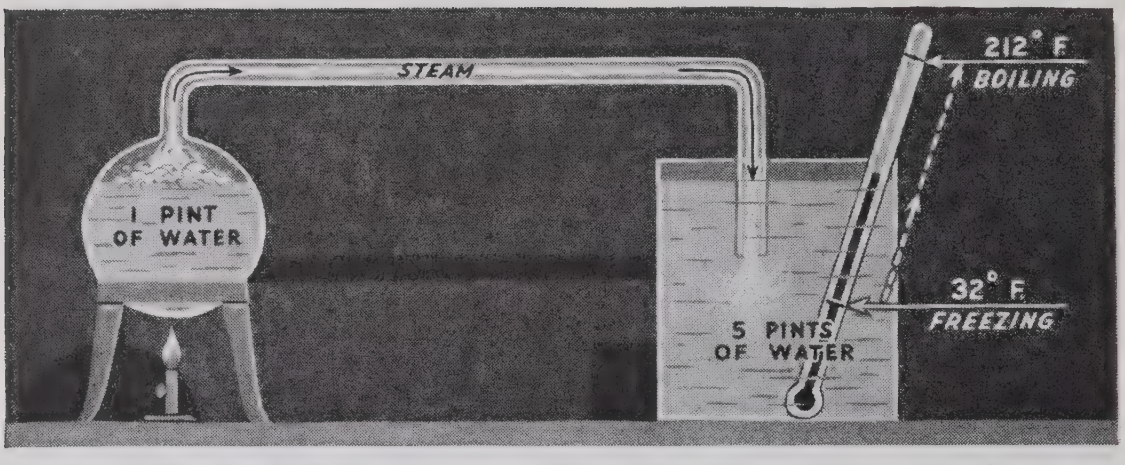


FIG. 217. Study this drawing carefully. It will help you to understand what is said in the last paragraph on this page.

water until enough steam has condensed to balance the added weights. Take the temperature of the water again.

b) Empty the can and put in the same amount of cool water as before (300 cubic centimeters). Take the temperature of some boiling water. Then pour 30 grams of boiling water into the can. How much does it warm the water in the can?

How did the temperature of the steam compare with the temperature of the boiling water? Which one warmed the cold water more? How much more? Why?

You remember what you learned about evaporating water. It cools things because each gram that evaporates takes a certain amount of heat. This heat causes the molecules to move much faster. What would you expect when steam or water vapor changes back to a liquid? The molecules must be slowed down. In other words, the heat that was required to change the liquid to a vapor must be taken out of the vapor again.

In your experiment you found that steam heated the cold water much more than boiling water heated it, even though the boiling water was the same temperature as the steam. Enough heat comes out of each pint of condensed water to heat more than five pints of water from freezing to boiling! The heat that comes out of a pint of

water when it condenses would heat thirty pounds of lead to its melting point and melt it. Or it would heat two pounds of iron white hot!

The immense amount of heat taken in when water evaporates or changes to steam is of great importance to anyone who evaporates water, condenses water vapor, or handles steam. Whenever water is heated to change it into steam, very large amounts of heat are required. Then when the steam changes back to water, the heat comes out of it.

That is one reason why steam-heating plants can be made very effective. Water takes up a great deal of heat in the boiler where the fire is. This heat changes the water to steam. As steam, it can be sent through pipes very rapidly for long distances. When the steam is cooled in the radiators, it condenses and gives out its great store of heat to warm the rooms.

Self-Testing Exercises

1. Why is a burn from steam worse than a burn from an equal weight of boiling hot water?

2. The steam that enters a radiator may be practically the same temperature as the water that leaves it. How has the room been warmed?

Problems to Solve

1. When water must be freed from minerals, it is distilled; that is, it is changed into steam and then condensed in another vessel. Why is this process expensive and slow?

2. Water in the form of steam is sent into the radiators of one room to warm it. Hot water is sent into the radiators of another room of the same size as the first. Which will require more pounds of water to warm it? Explain.

3. When does a vapor get the energy that is given out at the time the vapor condenses?

Problem 3:

HOW DO WE KEEP OUR BUILDINGS WARM?

HOW DOES A FIREPLACE HEAT A ROOM? It is pleasant to go into a well-heated room on a cold winter day. We do not roast on one side and freeze on the other; the air is not too dry; there are no unpleasant odors; and we do not have to open and close windows constantly to keep the room comfortable. Let us see how the principles of heat transfer and of evaporation and condensation are used to make our homes so comfortable.

FIG. 218. Benjamin Franklin invented this "stove" to set in the fireplace so that more heat would be thrown out into the room.

A fireplace is one of the simplest ways of heating a room. It probably developed from the open fire in the center of primitive huts. Like many primitive inventions, it is not very efficient. When a fire is started in a fireplace, the heat from the fire warms the air in the fireplace and the chimney. A convection current then moves up through the chimney. Unfortunately, this current carries much of the heat outdoors. The heat that warms the room must be transferred by radiation. Radiant energy goes out into the room from the fire, warming the walls, the furniture, and other objects. These warm objects then give heat to the air by conduction.

Fireplaces cost little and take up very little space. However, most of the heat goes up the chimney, making it necessary to burn much fuel in order to get enough heat, and the heat is not distributed evenly over the room.

To correct the great loss of heat in the ordinary fireplace, a new type of fireplace has been designed. It is called the *ventilating fireplace* (Figure 219). You can see from the picture what happens. Cold, fresh air from the outside enters through a pipe; then it passes upward behind the fire and over the top of it. The hot gases from the fire pass around this metal pipe, which is warmed by conduction. The heated air from the pipe then passes out through an opening in the front or side of the fireplace into the room. In this way much of the heat that is usually lost through the chimney is used to heat the air in the room.

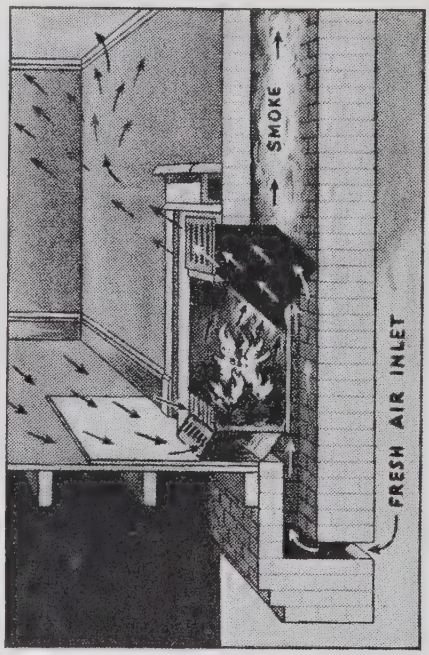


FIG. 219. Diagram of a ventilating fireplace

HOW DOES A STOVE HEAT A ROOM? Metal stoves placed in convenient positions in rooms cost little and are very efficient heating devices. The heat from the fire passes through the walls of the stove by conduction and sets up convection currents that carry the heat to all parts of the room. (See p. 266.) Stoves also heat by radiation. You may have believed that only glowing or *luminous* things, like the sun or a fire, radiate energy. However, almost every object sends out radiant energy. An object may not feel hot, but if it is warmer than things around it, it will lose heat energy to them by radiation.

HOW DO HOT-AIR FURNACES HEAT OUR BUILDINGS? Stoves, or heaters, as they are often called, take up much space, have to be cleaned and refueled often, cause considerable dirt, and are liable to cause fires. As you can

readily see, it would be much more convenient to have one source of heat for all of the rooms in a house rather than a separate fireplace or stove for each room. This convenience is supplied by our modern furnace.

A hot-air furnace is really a large stove in which the *fire box* is surrounded by an outer *jacket* filled with air (Figure 220). This jacket is connected with the rooms above by pipes, or *ducts*, that lead to openings in the floors or walls of the rooms. These openings are covered with metal gratings called *registers*. Many hot-air systems have cold-air pipes, or *returns*, that carry the air back to the furnace again. In systems of this type the warm-air register is on one side of the room and the cold-air register on the other side.

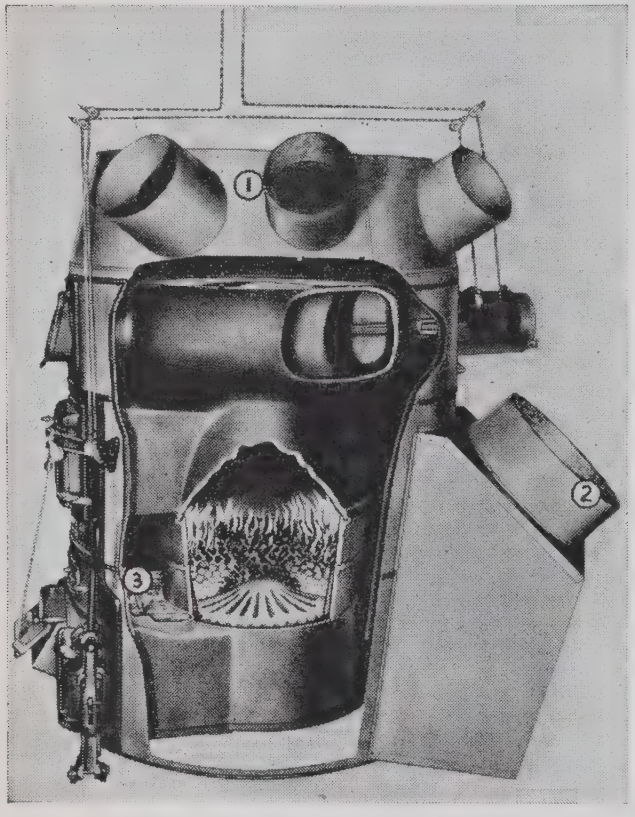


FIG. 220. A modern hot-air furnace. (1) Openings for hot-air ducts. (2) Opening for cold-air duct. (3) Water pan to humidify the warm air

When the air in the jacket of the furnace is heated, a convection current is produced. The cold air in the room sinks through the cold-air register and pushes the lighter and warmer air up through the warm-air ducts. The hot air passes across the top of the room and is cooled. It sinks on the opposite side of the room and goes down through the cold-air register. In this way there is a complete circulation of the air in the room. Sometimes a fan is added to make the air circulate more rapidly.

Some hot-air heating systems have no cold-air return to the furnace. A pipe from the outside brings fresh air into the bottom of the jacket around the fire box, and this air is warmed and circulated. This type of furnace requires more fuel than the type in which a cold-air return is used, because the cold air entering from the outside must be heated. It has the advantage, however, of providing fresh air to the rooms and thus securing better ventilation.

The hot-air heating system is probably the most commonly used central-heating system in homes. It has many advantages. It is simple to install and costs less than other types of heating systems. The air is heated rapidly, so that the furnace begins to heat the house almost immediately. Moisture is easily added to the hot air by a water pan in the furnace.

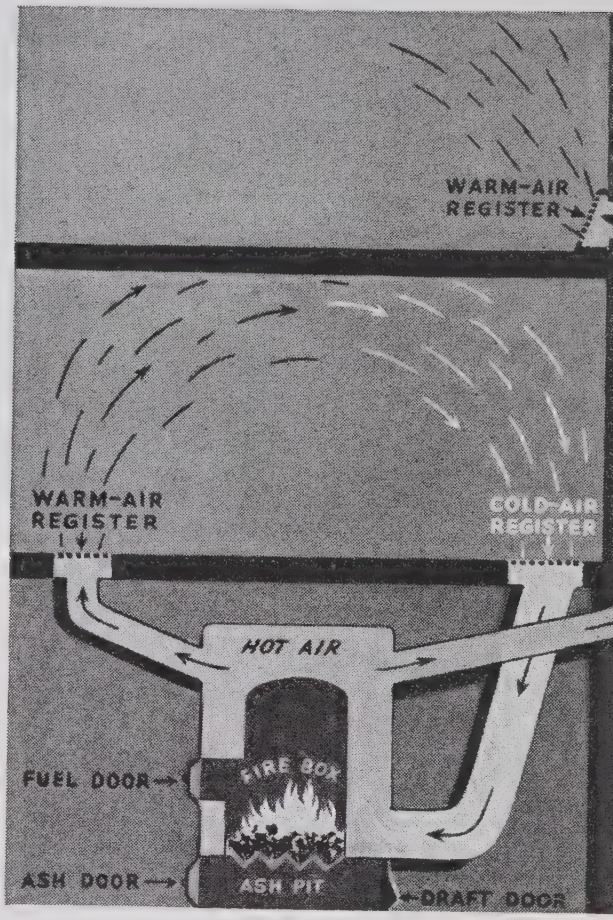


FIG. 221. How a hot-air heating system works

However, the hot-air furnace has some disadvantages as compared with other heating systems. It is rather hard to keep an even temperature throughout the house at all times. A strong wind may make one side of the house cold and the other side too warm. This trouble can be partly overcome by the use of forced circulation. Another disadvantage is that a small crack in the fire box may let smoke and poisonous gases go up to the rooms. But this is not likely to happen. A good hot-air system heats a small home cheaply and satisfactorily.

HOW DOES A HOT-WATER HEATING SYSTEM WORK? The hot-water heating system supplies heat to the rooms of a building in much the same way as the hot-air system. The fire box of a furnace is surrounded by a *water jacket*, or boiler, filled with water. The water also fills two sets of pipes connected with a *radiator* in each room.

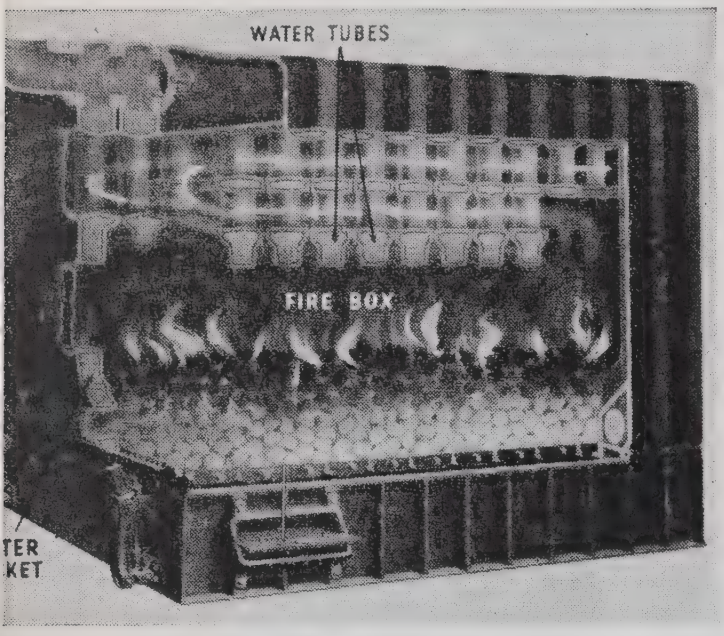


FIG. 222. Cut-away view of a hot-water furnace. Part of the water jacket is made of tubes so that more of the water can come in contact with the hot metal of the jacket.

When the water in the boiler is heated, cool water in one set of pipes pushes the hot water up the other pipes to the radiators. Each radiator is made of hollow metal pipes arranged to expose a great deal of surface to the air. Heat is conducted from the water through the metal of a radiator and into the air that touches the metal. Convection currents are immediately set up in the air, and the heat is distributed to all parts of the rooms.

As the water in the radiator gives out its heat and becomes cool, it sinks through the return pipe and enters the boiler again. Do you see that two important convection currents heat each room: (1) the current of water inside the pipes and radiators and (2) the currents in the air of the room?

Hot-water systems have one special feature that other systems do not have. If you should start a fire in a closed hot-water system full of water, expansion of the water would burst some part of the system. Some device must

be used to prevent this kind of accident and yet keep the pipes all full of water. The usual device for this purpose is an *expansion tank* placed above the highest radiator in the system (Figure 223).

The hot-water system has certain advantages. It keeps the temperature fairly even in all the rooms, and the heating plant is quite easy to operate. It begins to warm the rooms more quickly than steam, but it warms them more slowly than the hot-air system. It is economical of fuel, because once the water is heated, only a small fire is needed to keep it hot and circulating. The pipes and the furnace take up much less space than do those of a hot-air heating system.

Perhaps the greatest disadvantage of the hot-water system is that it costs so much to install. It is also necessary to provide a separate ventilation system. If the fire is allowed to go out for some time during the winter, the pipes must be carefully drained of water. Water left in the pipes may freeze, expand, and break. (See Experiment 19, page 139.)

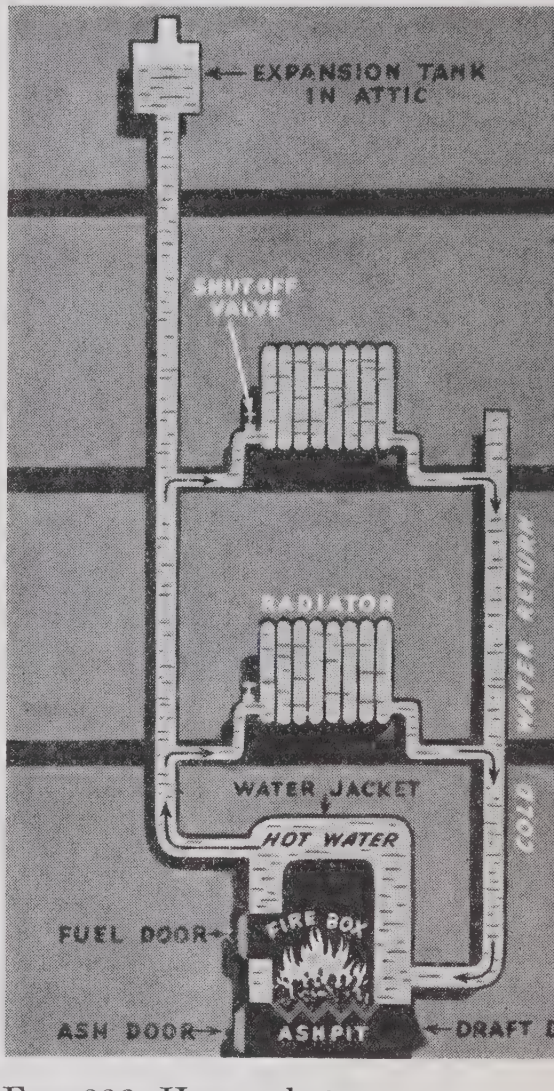


FIG. 223. How a hot-water heating system works

HOW DOES A STEAM-HEATING SYSTEM WORK? The construction of a steam-heating system is very much like that of a hot-water system. The water is heated in a water jacket or boiler around the fire box. However, the boiler is only partly filled with water. The heat from the

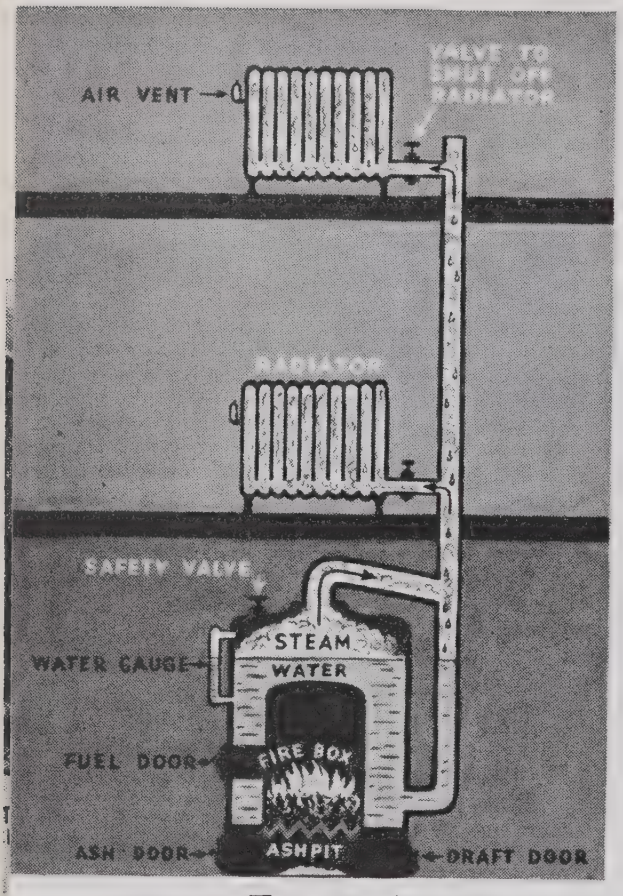


FIG. 224. How a steam heating system works

fire changes the water to steam, and the steam is forced upward through the pipes and to the radiators. In the radiators the steam condenses. As you know, when the steam condenses, it gives up the very large amount of heat that was needed to evaporate the water in the boiler. This heat warms the metal of the radiators, and the rooms are warmed.

The condensed steam then passes down through a pipe back to the boiler, where it is again changed to steam. In "one-pipe" steam systems the water returning to the boiler leaves the radiator through the same pipe used to bring the steam to the radiator. In other systems there are separate pipes for steam and water.

Steam-heating systems require several special devices to make them work successfully. Each boiler must have a *safety valve* to let steam out if for any reason the pressure becomes too high (Figure 224). A *water gauge*, or "water glass," is always used to show how high the water stands in the boiler. If the water gets too low, the boiler will be seriously damaged. Steam radiators must usually have *air vents* to let the air out so that the steam can come in. These little devices contain a special valve that is operated by heat. So long as cool air is escaping, they remain open. But when the hot steam reaches them, they close and keep it in.

Steam-heating systems are commonly used in large buildings, because the pressure produced by the steam

forces the steam rapidly through the pipes and radiators. The result is that rooms a long distance from the furnace may easily be heated. The cost of installing a steam heating system is higher than that of a hot-air heating system, and a steam system provides no method of ventilation.

Self-Testing Exercises

1. Why is a stove more efficient than a fireplace?
2. In what ways is a hot-air system like a hot-water system? In what ways is it different?
3. Why do the radiators of a steam heating plant get hotter than the radiators of a hot-water heating system?
4. If you were going to build a house, what kind of heating system would you choose? Why?

Problems to Solve

1. Of all the heating systems described in this book, which one radiates no heat into a room?
2. What kind of heating system is most common in your community? What are the reasons for its use there?
3. A convection current is necessary for the working of every common heating device that uses fire. What does this current do in each device?
4. Find out about vapor, vacuum, or low-pressure heating systems. What is the advantage of this type of system?
5. Find out about different kinds of hot-air furnaces. What are the advantages of each type?
6. Find out how automatic coal stokers work and how they cut fuel costs.
7. Find out how thermostats regulate the temperature.

HOW CAN THE HEAT BE KEPT IN OUR BUILDINGS? You have learned how good conductors with special arrangements of pipes and other devices are used to transfer heat from fires to the rooms where you live. It is almost as important to know how to keep the heat inside our homes.

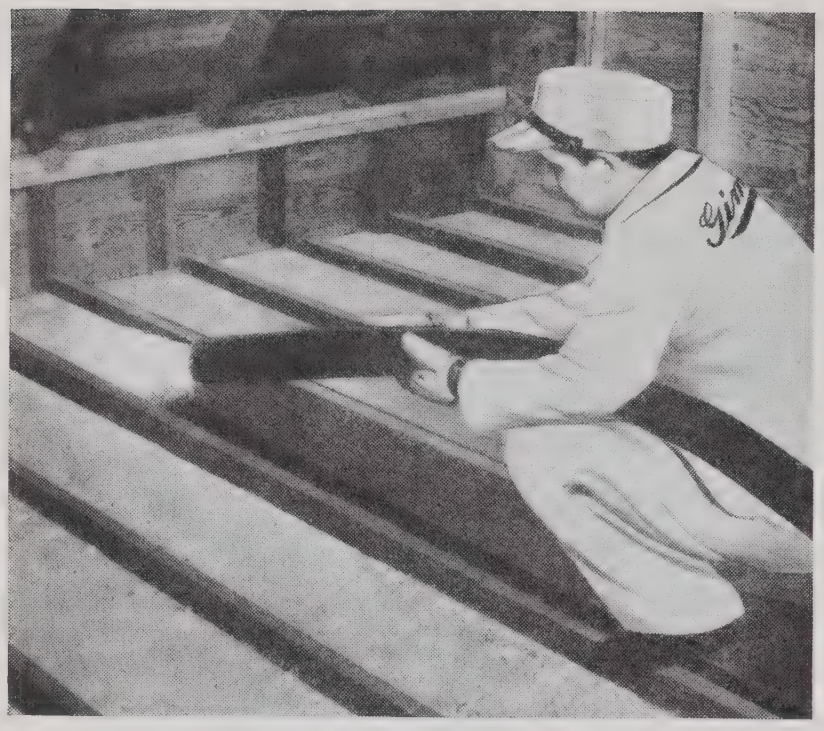


FIG. 225. This man is insulating an attic by filling the spaces between the beams with insulating material. Materials like this are also blown into the space between the inner and outer walls of a house.

The insulating materials commonly used are incombustible and are treated with chemicals so that insects will not nest in them or feed on them. Asbestos and certain materials made of rock are popular insulators.

Houses are made much more comfortable when we apply our knowledge of heat transfer to the problem of preventing the escape of heat from the house. In addition, the cost of heating the house is lowered.

Heat can escape from our buildings in three ways: (1) It can be conducted through walls and windows. (2) It can be carried out of the house with the air that passes through porous walls and through cracks around windows and doors. (3) It can be radiated through windows.

To reduce these losses of heat we can do several things. Cracks around window and door casings should be filled. Special putty-like materials are sold for this purpose. "Weather-strips" around window-sashes and doors are also a great help. Next in importance is the use of extra windows, or storm windows, outside the regular windows. A great deal of heat is lost by conduction through glass. Two windows with an air space between them greatly reduce this heat loss.

The last important way to keep heat in our buildings is to use good insulating materials, or non-conductors, in the walls and under the roofs. The walls of wooden houses are usually double with air spaces in them. Such houses are made much warmer in winter if these spaces are filled with good insulation, such as mineral wool. A layer of good insulation between the ceiling and roof of almost any building also helps to reduce the loss of heat by conduction. Insulation is also valuable in summer because the heat is kept outside, and the house remains cooler.

FIG. 226. The window at the right is ready for winter with its storm window in place.

Self-Testing Exercises

1. State the three ways in which heat is lost from poorly constructed buildings.

2. What are the most important ways of preventing loss of heat from a home? Explain why each one helps.

Problems to Solve

1. Examine your own home and decide whether the heat loss is serious in cold weather.

2. What are common insulating materials made of, and why are they non-conductors of heat? Watch for advertisements and prepare an exhibit of different kinds of insulation.

3. How would the addition of storm windows to a house make the air warmer near the floor? Draw a diagram to show how it would affect the convection currents in the room.

4. Attic rooms are often too hot to use during the summer. What could you do to make such a room comfortable?

5. Why are basement rooms usually the coolest rooms of a house during hot weather?

FIG. 227. Until modern science showed men how to control heat, ice could be obtained only by cutting it from lakes, ponds, and rivers in winter. The ice was then stored in insulated ice-houses and covered with some insulating material like sawdust or straw. In this way part of the ice could be kept all summer. However, the ice often contained disease germs or dirt, and in many places the winters were not cold enough to form thick layers of ice.

Problem 4:

HOW DO WE KEEP THINGS COOL IN WARM WEATHER?

IN WARM WEATHER many kinds of food and many drinks are much more appetizing if they are cold. In such weather we also like to have the air in our buildings cool. But it is even more important that foods such as milk and meat be kept from spoiling. The bacteria and other living things that cause milk to sour and fresh meat to decay grow very rapidly at summer temperatures. Therefore these foods must be used up quickly unless there is some way to keep them cool. If foods can be kept at a temperature of 40° F. and lower, the bacteria that cause them to decay cannot grow.

For a long time the only practical way to keep food cool was to use cool cellars, cool water from wells and lakes, and ice from lakes and streams. These methods are still used in many country homes. However, many years ago machines for making ice were invented. The artificial

FIG. 228. A modern ice-making plant. The floor is really tops of cans full of water and partly submerged in a solution of salt and water. Nine of these cans are seen pulled up out of the salt water. In the background is the machinery that compresses the vapor, keeps a partial vacuum in the vaporizing pipes, and in other ways operates the plant. Figure 231, page 301, shows how such a plant works.

ice made by machines had so many advantages that it soon took the place of natural ice wherever it could be made. Today great refrigerating and cold-storage machines are found in almost every town or city of any size. And every home that is supplied with electric current may have a small electric refrigerator to keep food cool and to make small amounts of ice. Homes without electricity may have refrigerators that burn kerosene or illuminating gas to keep them cool!

HOW CAN ICE BE MADE IN A WARM PLACE? In order to make water freeze in warm weather or to make the inside of a box or room cool, something must be done to make heat go backward; that is, heat must be made to move from a cool place to a warm place. Can you imagine how a machine can do this?

Probably you know that ice-cream is frozen by putting a mixture of ice and salt around a can that contains a mixture of cream and other materials. Of course, water could be frozen in the same way, but you would need ice

to start with. You can make a little ice for yourself without having anything cold to start with. To do this you will need to use the process of evaporation.

Experiment 40. *How Can Ice Be Made by Evaporation?* Put three or four drops of water in the center of a large flat cork. On the water place a thin, concave glass dish known as a "watch glass." The experiment will work best if the watch glass is at least three inches in diameter. Set the cork and dish in a well-ventilated place away from any flame. Fill the dish almost full of ether. Fan the ether vigorously with a piece of cardboard or a folded newspaper.

When the ether has almost evaporated, you should see a ring of frost on the under side of the watch glass. Lift the watch glass by the edge. Why does the cork stick to the glass? Explain what has happened. You may be able to understand better what happened if you repeat the experiment while someone holds the bulb of a chemical thermometer in the evaporating ether and calls out the temperature from time to time.

You know from Problem 2 that much heat is required when a substance evaporates. Ether evaporates much faster than water. Fanning the ether drives the ether vapor away and helps the liquid to evaporate even faster than it would without fanning. This rapid evaporation takes heat out of the liquid ether until its temperature is below 32° F. The warmer water gives up heat by conduction through the watch glass into the ether until the water freezes.

The ether and dish in this experiment formed a small ice machine. However, you can see that ice made by this plan would be very expensive. The ether or other liquid used to lower the temperature is evaporated and lost. Let us see how the inventors have solved the difficulties of making things very cold by evaporation.

HOW DO REFRIGERATING MACHINES WORK? To find out how artificial cooling machines work, we will examine an electric refrigerator. First of all, such a machine must have something to hold the evaporating liquid. This *evaporator* is a box-like part inside the refrigerator near the top, and surrounded by coils of pipe. In the box are trays to hold the water for making ice. The pipes of the evaporator are, of course, gas tight.

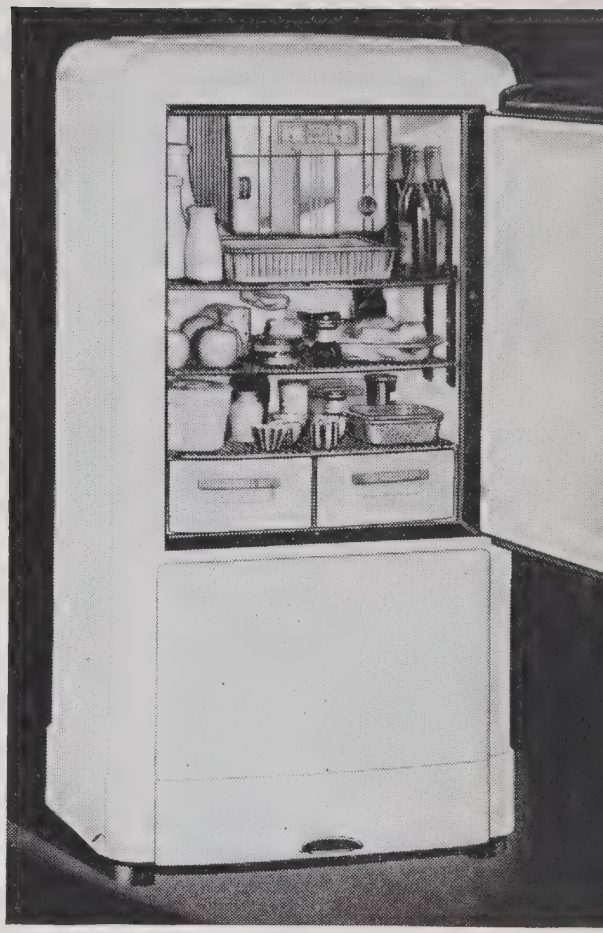


FIG. 229. A modern electric refrigerator. The evaporator and ice-making box are seen at the top.

Some kind of liquid that evaporates easily is placed between the walls, and the air is pumped out. Removing the air allows the liquid to evaporate more rapidly. The heat required for the evaporation is taken from the water in the ice trays and from the air in the refrigerator. The rapid evaporation of the liquid soon cools the evaporator to a very low temperature, water freezes in the trays, and the food compartments become very cold.

But soon the space above the liquid has all the vapor it can hold, and evaporation stops. You can see that the refrigerating machine needs some more parts to take the vapor out and to let the liquid keep on evaporating. The vapor is removed by a pump commonly called the *compressor*. And of course there must be something to run the pump. That is what the electric motor does. The pump is connected to the top of the evaporator by a pipe. When

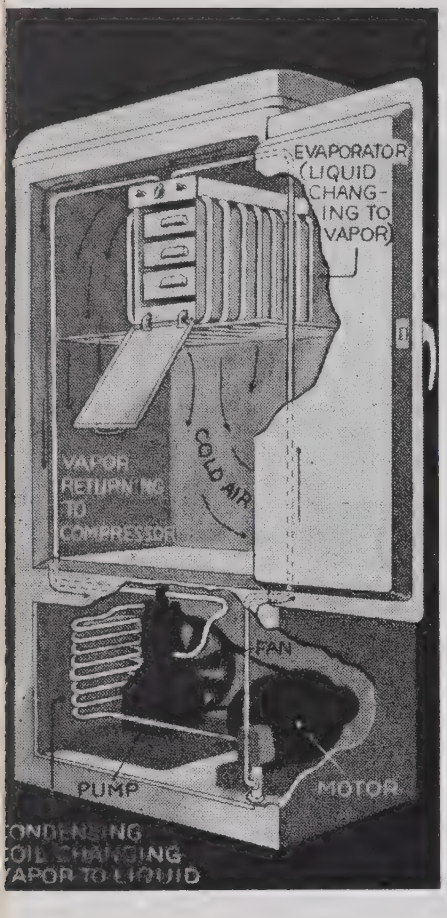


FIG. 230

the pump runs, it removes the vapor from the evaporator; then more liquid can take up heat and evaporate.

This vapor is too expensive to throw away; so there must be some way of saving it to use again. The part of the machine that saves the vapor is called the *condenser*. The condenser is made of coils of pipe. Sometimes it looks like a small automobile radiator near the electric motor. Sometimes it is a round coil of pipe on top of the refrigerator. In the condenser the molecules of vapor are squeezed close together by pressure. This makes them condense, or change back into a liquid, if they are kept cool.

But compressing a gas makes it warmer, and this warmth keeps the vapor from condensing. Therefore there must be something to remove heat from the condenser. This work is done by the air. The vapor in the condenser is warmer than the air of the room; therefore heat is conducted through the condenser pipes into the air. A fan attached to the motor blows the warm air away and brings cooler air to take up more heat. Or, if the coils are on top of the refrigerator, convection currents carry the heated air away fast enough so that no fan is needed.

As the air carries the heat away from the vapor in the pipes, the vapor condenses and gives out all the heat it took from the inside of the refrigerator while it was evaporating. Then the liquid goes back into the evaporator and gets some more heat. This process is repeated over and over again. A thermostat operated by electricity turns the current on for the motor when the ice-box falls

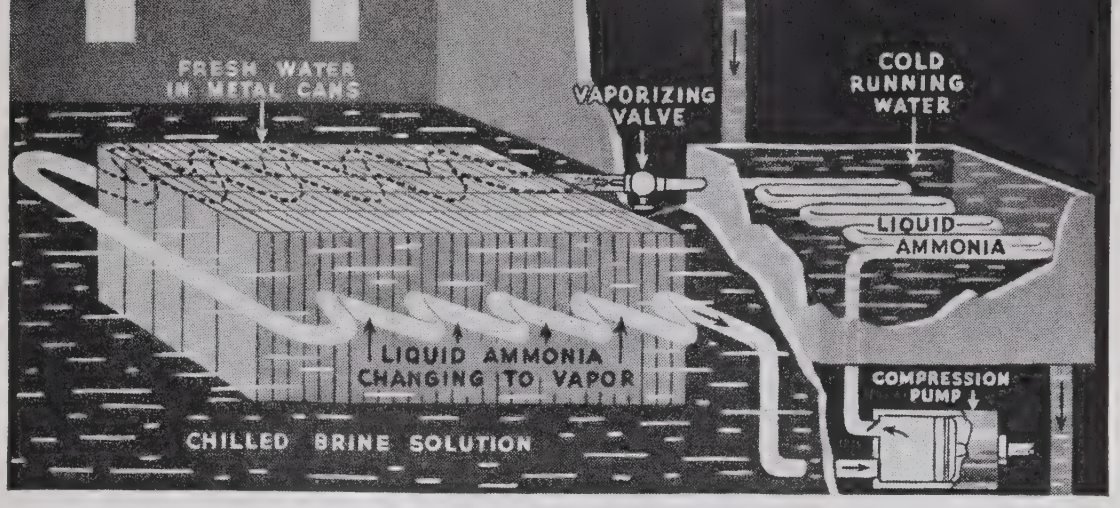


FIG. 231. Study this diagram of an ice-making plant carefully until you are sure you can explain exactly how such a plant works. What you have learned about home refrigerators should enable you to explain the ice-making machinery. Be sure that you can explain what the vaporizing valve, the cold running water, and the compression pump do.

to a certain temperature. It also turns off the current when the ice-box is sufficiently cooled. Most ice-boxes have regulators that can be set to make the box colder or warmer.

The liquid used in many home refrigerators is sulphur dioxide. Sulphur dioxide is the gas that is formed when sulphur burns. Ordinarily it is a gas, but it is rather easily condensed into a liquid for use in refrigerators. Scientists have found a number of other compounds that can also be used for the same purpose. Liquid ammonia is the compound most commonly used in large artificial ice plants and cold-storage plants.

In an ice plant or a cold-storage plant the evaporation of the ammonia cools a concentrated solution of salt, or calcium chloride, called *brine*. Since a solution freezes at a lower temperature than water, the brine can be made very cold without freezing. Then it is circulated around tanks of water to make ice. Or it is sent through pipes to take the heat out of rooms where meat and other foods are stored.

What a mechanical refrigerating machines does, then, is to cool the inside of a refrigerator or a tank of brine by

allowing a liquid to evaporate very rapidly. The vapor that is formed is then compressed and condensed so that it gives up its heat in another part of the machine. The unwanted heat is carried away by a current of air or a stream of water. Of course, good heat-insulating materials are used in the walls of refrigerators and of cold-storage rooms to help prevent the entrance of heat from the outside during warm weather.

Self-Testing Exercises

1. Tell how the evaporator in Figure 230 is made very cold.
2. Why is a fan usually placed where it will blow air on the condenser pipes of an electric refrigerator?
3. Why does an electric refrigerator need a motor?
4. Some boys and girls think an electric refrigerator is kept cool by the ice cubes in it. Why is this idea wrong?

Problems to Solve

1. Why was a cork used under the glass in Experiment 40?
2. Trace the heat from a tray of ice cubes in an electric refrigerator or from a can of ice in an ice plant to the outside air. Remember to tell where it is conducted through metal, where absorbed by evaporating liquid, where carried by circulation, etc. Use the diagrams of the book to help you.
3. Why does a refrigerator get warm after the motor stops or all the ice melts (if it is an ice refrigerator)?

HOW ARE BUILDINGS AIR-CONDITIONED? Many theaters, some stores, and a few homes are now "air-conditioned." Complete air-conditioning includes several things. In air-conditioned buildings the air is kept at the most comfortable temperature—warmed in the winter and cooled in summer. The amount of water vapor in the air is kept at the correct level—increased in the winter and decreased in the summer. Dust in the air is filtered or washed out.

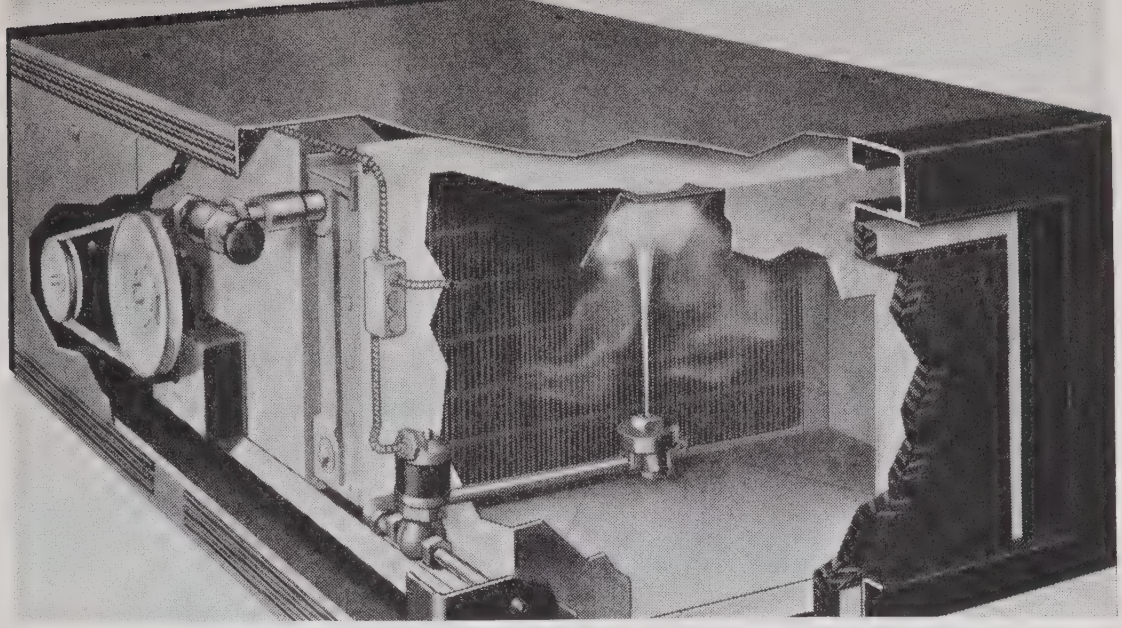


FIG. 232. This is a humidifier for use in homes. It is connected to pipes that lead to the rooms. Notice the spray of water. A fan blows the moist air up through the pipes.

We usually think of air-conditioning in connection with the cooling of the air in hot weather. This requires a refrigerating machine that works like an ordinary electric refrigerator. As in a cold-storage building, the machine cools brine. The brine is then circulated through pipes over which the air is blown by large fans. Or water is cooled and sprayed through the air. Usually the air is cooled below the required temperature. This causes some of the water vapor in it to condense. Afterwards the air is warmed up to room temperature. It can then evaporate the right amount of perspiration from our skins to keep us comfortable.

The air-conditioned cars on railroads are cooled in several ways. One plan is to put large cakes of ice in boxes underneath the cars. Air from inside the cars is blown over the ice to cool it and take out excess moisture. In other plans the air is cooled by a refrigerating machine operated by electricity or by steam.

Good insulation is just as important in keeping a building or a railway car cool as in keeping it warm. If heat gets in through the walls almost as fast as the refrigerating machinery takes it out, air-conditioning is too expensive

to be practical. Buildings and cars that are air-conditioned are tightly constructed with well-insulated walls and often with double windows.

Self-Testing Exercises

1. What is meant by the complete air-conditioning of a building?
2. How is the air of air-conditioned buildings cooled?
3. How is the unwanted water vapor removed from the air in air-conditioned buildings?

Problems to Solve

1. How are refrigerator cars and refrigerated trucks cooled? Look in an encyclopedia under the topic, "Refrigeration."
2. If you have an air-conditioned theater or store in your locality, make arrangements with the manager to see the machinery and learn how it works.

LOOKING BACK AT UNIT 6

1. With the Table of Contents before you as a reminder, write down a list of what you think are the important ideas in this unit.
2. Which ideas do you think are most interesting and valuable?
3. Show that you know the meanings of the following terms:

conduction	*heat insulation*	*water gauge*	*wet-and-dry bulb thermometer*
convection	*expansion tank*	*air vent*	
radiation	*safety valve*	*humidity*	*brine*

ADDITIONAL EXERCISES

1. Make a wet-and-dry-bulb thermometer from two cheap thermometers: Select two thermometers that read about the average of all those shown in the store and that read alike. Fasten both to a board of convenient size. Remove the metal guard from the bulb of one thermometer and slip over it a piece

of linen cloth that you have sewed into a tube of suitable size. Find in some science book a table giving the humidity for different readings. Then measure the humidity in your home, in your classroom, and outdoors when the air is above 32° F. Remember that the wet-bulb should be fanned before a reading is taken.

2. See how low a temperature you can obtain by evaporating ether or alcohol from a cloth wrapped around the bulb of a thermometer.

3. Tack cloth all around a cubical wooden frame. Place a thermometer so that its bulb will be inside the inclosure, but the scale will be where you can read it. Wet the cloth and see how cool the inside of your "refrigerator" will get. Many campers use this plan for keeping food cool.

4. Obtain a small porous flower-pot. Seal up the hole in the bottom with a cork and some paraffin. Hang the pot up and fill it with water. Also fill a tin can with water. See how much cooler the water stays in the pot than in the tin can. Why does it stay cooler?

5. How can a single compressor in the basement keep several refrigerators in a building cool?

6. Why is a fan not needed when the condensing coils are placed on top of the refrigerator?

7. Compare a refrigerating machine with a steam-heating system. Begin by thinking where evaporation and condensation take place, where the coolest and the warmest parts are, where the systems get the energy to make them work, etc.

8. The first thin coating of ice on a pond may form overnight, but after a long time the ice may be only an inch or two thick. Give at least two reasons why the ice gets thicker so slowly.

9. Salt makes ice melt. Why does a mixture of salt and ice go far below the temperature of the ice that is put in?

10. Plan and carry out an experiment to find whether copper or iron conducts heat more rapidly.

11. Cold cannot be radiated because cold is only the opposite of heat. Keeping this fact in mind, explain why your hand feels cooler when it is held at one side of a large cake of ice.

12. Why is a snow house good protection from cold weather in the arctic regions?

13. Drop some small pieces of ice in a test-tube and then drop a small rock on top of the ice to hold the ice in the bottom of the test-tube. Heat the upper part of the test-tube until it boils. What evidence does this give you as to whether water is a good conductor or a poor conductor of heat?

14. One man reported that painting his automobile top with aluminum paint made the car ten degrees cooler on a sunny day. Do you think this could be correct? Why?

FIG. 233. Long before men had any scientific knowledge of weather, they knew that the movement of the air had much to do with weather. Wind vanes have been in use for hundreds of years, telling people which way the wind is blowing. In this unit you will learn just how important the movement of the air is in the changes that take place in the weather. (Ewing Galloway, N. Y.)

UNIT SEVEN

UNIT 7

WHAT MAKES THE WEATHER CHANGE?

INTRODUCTORY EXERCISES

1. Make a list of the words used to describe weather. What do these words tell you about the weather? For example, the word "hot" tells you about the temperature.

2. What signs tell when it is likely to rain, snow, get hotter, or get colder?

*3. How can water vapor in the air be condensed, or changed to liquid water?

4. What is a wind? What makes the wind blow?

5. How is the air warmed?

*6. What happens to air when it is heated?

*7. What are the two kinds of thermometers that are commonly used?

8. You can learn a great deal about weather by making observations over a period of time. A thermometer and a barometer are the chief instruments you will need. You can make a barometer as suggested in Problem 6, page 343, or you can take the barometer readings from daily weather reports in a newspaper.

Prepare a chart like the one below to record your observations. Under the column headed *Condition of Sky* the following symbols may be used: If you judge the sky to be more than two-thirds cloudy, use the symbol ●. If the sky is from one-third to two-thirds cloudy, use the symbol ◐. If the sky is less than one-third cloudy, use this symbol ○. In the column headed *Kinds of Precipitation* list rain, fog, snow, sleet, or hail. In the column headed *Direction of Wind* write the direction from which the wind is blowing.

Date	Time	Atmospheric Pressure	Temperature	Direction of Wind	Condition of Sky	Kinds of Precipitation
March 1	9:00 A.M. 4:00 P.M.					

FIG. 234. The United States Weather Bureau tries to take the guess out of weather forecasting by the use of many scientific instruments and observations. The man in the corner is looking at a triple register, which records the velocity and the direction of the wind and the amount of sunshine or rainfall.

LOOKING AHEAD TO UNIT 7

DID YOU ever try to predict what the weather is going to be? Perhaps you think that you have never done so. However, if you have ever looked at the sky and said, "I think it is going to rain," or "I believe it will be hot today," you were predicting, or forecasting, the weather.

It is no wonder that nearly everyone is interested in the weather. Weather makes us comfortable or uncomfortable. It determines whether or not we will go on a picnic. It determines the kinds of clothes we wear. We usually consider the weather when we make our plans for the day. It affects so many things we do that it is no wonder people frequently ask, "What's the weather today?"

Of course, weather is something that neither you nor anyone else can control. If the conditions are right, it will rain; if not, it will not rain. Scientists have learned how to regulate the weather in our homes, but they cannot change the weather outside. There is only one thing that scientists

can do about weather. They can predict quite accurately what the weather is going to be. Scientists know what conditions cause rain, snow, or fair weather, and they usually can tell whether these conditions will be present during the next twenty-four or forty-eight hours.

Long before scientists discovered how different kinds of weather are produced, man tried to predict the weather. He watched the sky, felt the air, observed the direction of the wind, and noticed whether it was getting warmer or colder. As a result of these observations he discovered that when certain conditions are present, a certain kind of weather usually follows. He did not know why this was true; he merely knew that it was true. For example, he found that when the wind shifted into the east, it was likely to rain. Perhaps you have heard the old weather saying, or proverb, "When the wind veers to the east, 'tis good for neither man nor beast."

There are hundreds of these old sayings; they represent the long experience of men regarding those changes in the air that cause changes in weather. Many of these old sayings may be used to predict weather quite successfully.

Weather Goes Topsy Turvy All Over U.S.

Topsy turvy weather prevailed over the United States yesterday.

In Chicago the mercury rose to 69 degrees, an all-time high for Nov. 23 and the equal of the highest mark ever recorded so late in the season. Bathers frolicked in Lake Michigan—not many, but some. Today, according to the official forecast, there may be rain and the temperature may fall sharply in the afternoon or evening.

Rochester, N. Y., reported a high yesterday of 74 degrees, a mark that has not even been approached at this date since 1887, when 71 was the maximum. New York, Albany, Philadelphia, Pittsburgh and Washington each had a summertime high of 72 degrees. It was a perfect June day almost everywhere east of the Mississippi.

Subzero, Snow in West

But in the west it was altogether different. In the Rocky mountains snow lay deeply drifted and there

FIG. 235. From what you are learning in this unit you should be able to understand this weather story that was printed one day in a newspaper.

were many places the thermometers registered from 10 above down to 12 below zero.

Near Los Angeles the orange and lemon growers battled to save their orchards in temperatures ranging from 23 to 29 degrees. Icicles hung on eaves and frost coated the California meadows. The pepper and lettuce crops were severely damaged. Reports said that the smudge pots, from which the orange and lemon growers had been pouring black smoke for three nights, were being kept going at full blast.

Warm Weather in East

Isotherms, those dotted lines sweeping across the weather map to indicate places of equal temperature, usually run in a general east and west direction. Yesterday they lay over the central United States in a general north-south direction. To the east it was warm, to the west cold.

There were heavy rains just west of the Mississippi, and a train wreck at Indianola, Ia., was attributed to a washout of the track. The official explanation of the freakish weather was that a "trough" of low pressure, squeezed back by a tarrying of high pressure centered over Virginia, was preventing the western storms with their snows and low temperatures from backing through to the balmy east.

Everything that you study in science should be a great help to you in reading newspapers and magazines more intelligently.

But some of the proverbs concerning weather are nothing but superstitions. For example, many people still believe that we will have six weeks of bad weather if the ground hog sees his shadow on February 2. Others believe that the thickness of fur grown by squirrels and other animals in the fall is a sign of whether the winter will be cold or warm. Many such weather sayings are false because they are based on things that have no real connection with the weather.

Make a list of the "sayings" you have heard used to tell what the weather will be; for example, "When the sun sets red, it will be a clear day tomorrow." Many of these sayings are just superstitions; others are really valuable in predicting the weather.

Keep your list, and, as your study progresses and you learn more about weather, write the word "Superstition" after those signs and sayings that cannot be explained by the facts of science. Write "Scientific" after those that can be explained by the facts.

There are, then, two kinds of weather sayings: those based upon actual observation and those based merely on superstition. How are we to tell which sayings are correct

and which sayings are incorrect? How can we become fairly accurate in predicting what the weather is likely to be? The best way to learn how to predict the weather for yourself is to understand how changes in weather are brought about. What makes it rain? What makes the wind change direction? How does a change in the direction of the wind bring changes in weather? These are only a few of the questions you need to be able to answer to understand changes in weather.

Problem 1:

WHAT CAUSES THE DIFFERENT KINDS OF WEATHER?

How do we describe weather? Usually one of the first things we do in the morning is to peek outside to see what the weather is. We look at the sky to see whether the sun is shining, at a thermometer to see how warm or cold it is, and at the trees to see how hard the wind is blowing. If we have a morning paper, we read the weather forecast. Or we may turn on the radio and hear the weather forecast. From this information we get an idea of what the weather will be for the day.

The words that we use to describe weather really tell us what weather is. We look at the sky, and we say that it is fair, clear, cloudy, rainy, foggy, or snowy. These words are used to tell what is happening to the moisture content of the air. If it is fair, or clear, moisture is not coming out of the air. If it is cloudy, rainy, or foggy, the water vapor in the air is condensing, that is, it is changing to liquid water.

Sometimes we say that the air is "muggy," humid, or dry. Here we are describing how the air feels to us. If the perspiration does not evaporate quickly from our bodies, we say that the air is humid. By this we mean that the air

FIG. 236. Because the weather reports in the newspapers and over the radio predicted rain or snow for the day, hundreds of people protected themselves by wearing heavy coats and carrying umbrellas.

contains a great deal of water vapor. If our skin feels parched and perspiration evaporates quickly, we say that it is "dry" weather. Usually when we describe weather, we use some word or words to tell about the moisture in the air.

No description of weather would be complete without some mention of the temperature of the air. We say that it is cold, cool, warm, or hot. Often we say that it is cooler or warmer. What we mean is that the temperature is higher or lower than it was the day before.

Another important part of weather is the way the air is moving. We describe the movement of the air by saying that the weather is calm, still, windy, or breezy. We tell the direction of the wind by mentioning the direction from which it is blowing. A north wind, for example, is a wind blowing from the north. This movement of air, as you will learn later, is a very important part of weather.

From this description you can see that the weather at any time is made up of the way the air is moving, the temperature of the air, and the condition of the moisture in the air. That is, the weather where you are is simply the

condition of the air in your locality. Now let us find out what causes the different kinds of weather.

HOW IS THE AIR WARMED? As you already know, the air covering of the earth is warmed by the sun. You also know (page 269) that the radiant energy from the sun passes through the air without warming it very much. Therefore the radiant energy from the sun must be absorbed by some other material and changed to heat before it can raise the temperature of the air. This happens when the radiant energy strikes the surface of the earth. The top layer of soil becomes warmer and warmer as the sun shines on it. So does the water surface of the earth, and so do the rocks.

The air in close contact with the earth receives heat from the warm earth's surface. This heat passes by conduction from the earth to the cooler air. As you know, when air is heated, it expands and becomes lighter. The colder, heavier air farther above the earth sinks and pushes up the lighter, warmer air. The air that sinks then receives heat from the earth, and it, in turn, is pushed upward by cooler air sinking from above. Thus the air covering of the earth is warmed by the heat from the rocks, soil, and water, which get their heat from the sun.

Self-Testing Exercises

1. Why does a thermometer in the sun register a higher temperature than a thermometer in the shade?

2. The top of a mountain is much nearer to the sun than a valley is. Why is the temperature higher in the valley than on the mountain?

WHY DOES THE WIND BLOW? If you remember what you learned about convection currents in Units 4 and 6, you already know why the wind blows. A wind is just an enormous convection current that extends over a

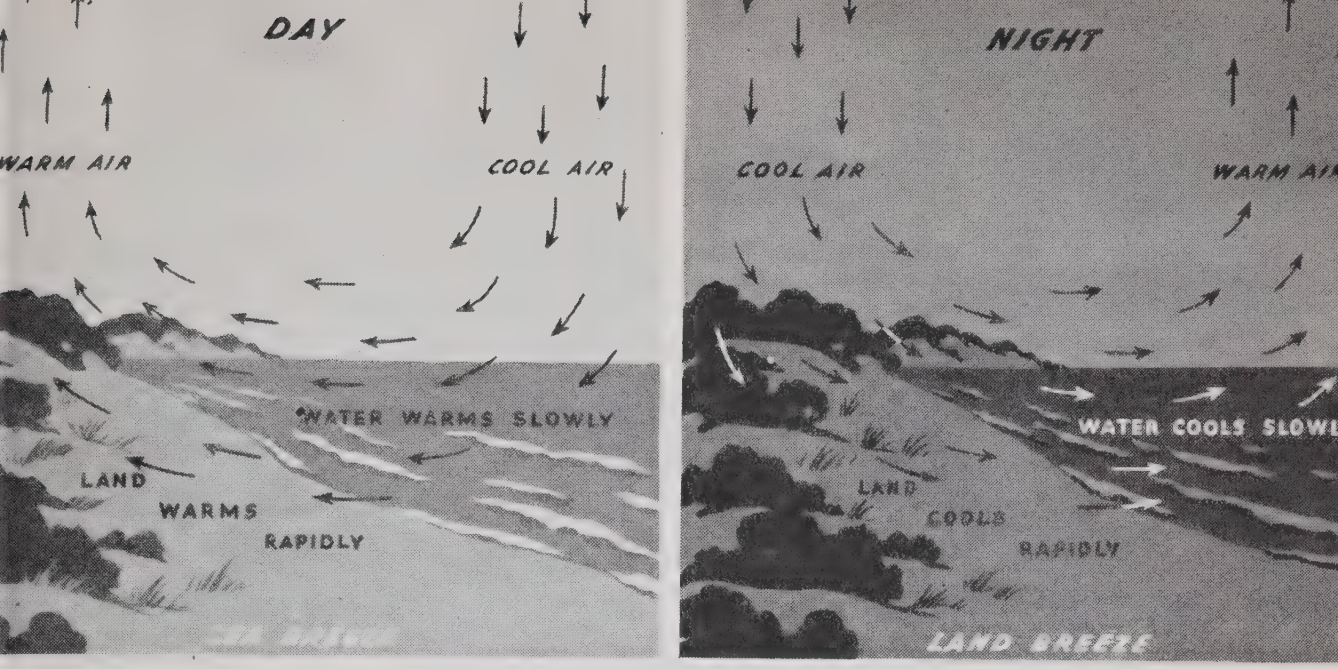


FIG. 237. During the day when the air over the land is warmer than the air over the water, a breeze blows toward the land. At night, when the air over the land is cooler than the air over the water, a breeze blows toward the water.

wide region. It is produced in the same way that a convection current is produced in a room where there is a stove. All that is needed for the air to move is that it weigh more at one place than at another.

As you already know, a cubic foot of cold air weighs more than a cubic foot of hot air. Therefore, when the air is cold, the air pressure will be greater than when the air is hot. The cold air will sink, flow along the ground, and push up the warmer air. This movement of the air along the ground is what we call a *wind*.

Many of the changes in wind direction are caused by changes in the temperature of two places near each other. For example, suppose that you live on the shore of a large body of water. The sun warms both the land and the water, but the water does not get warm as quickly as the land. Therefore the air over the land is warmer than the air over the water. If the difference in the weight of the air becomes great enough, the heavier, cooler air over the water will force the warm air over the land upward. Thus we have a sea breeze or a lake breeze along the shore.

If you live in a valley, you have probably noticed the cool wind that flows down the side of the mountain after a hot day. Up on the mountain the air is less dense, and the heat from the soil and rocks is radiated out through the thin air quite rapidly. In a valley the air is denser; it therefore acts as a blanket to keep the heat from escaping rapidly. At night the difference in pressure between the high, cool air and the low, warm air becomes so great that the cooler air flows down the mountainside and pushes up this warmer air in the valley.

There are, of course, many other conditions that produce local winds. The air over forests is cooler than the air over grasslands. The air over grasslands is cooler than air over plowed fields. Differences in the temperature of such places close together thus bring about light breezes. These winds, however, affect only small areas. They bring about changes in temperature and weather conditions for a distance of only a few miles. A shift in the wind in Chicago so that the lake breeze flows toward the land may make the temperature twenty degrees cooler. Ten miles inland, however, the temperature may not change.

The winds that bring about changes in weather over wide areas, however, are not caused by local conditions. The changes in the direction of the wind and in the speed of the wind over wide areas are the result of the movement of large "whirlpools" of air across our country.

The direction of the wind and the temperature of a place are closely related. A change in the direction of the wind over wide areas will bring about a change in temperature. Usually when the winds shift to the north and west, it becomes cooler; the opposite is true when winds shift to the south. You will learn more about winds in Problem 2.

Self-Testing Exercises

1. Explain how changes in temperature change the density of the air. Explain how a change in the density of air changes the pressure of the air.
2. Explain how winds are produced.

WHY DOES THE MOISTURE IN THE AIR CHANGE? First, let us review a few facts that you already know. Water poured into an open pan will disappear if it is left for a while. Wet clothing soon dries. After a rain the streets and ground become dry. You know that in each of these cases the water evaporated; that is, it changed to a gas, or water vapor, and its molecules mixed with the other kinds of molecules that make up the air.

You might think that water will always evaporate into the air. Can you think of any condition in which evaporation will not take place?

EXPERIMENT 41. *Is Water Always Evaporating into the Air?* Obtain two wide-mouthed bottles or beakers. Fill each bottle half full of water. Be sure that you pour the same amount of water in each. Paste a paper on each bottle to show the height of the water in the bottle. Cork one bottle and leave the other open. Allow them to stand for several days. Each day measure the amount of water that has evaporated by measuring down from the edge of the paper.

Does water evaporate from both bottles? Does water keep evaporating in the bottle that is corked, or does it stop evaporating? Does water continue to evaporate from the open bottle, or does it stop evaporating? How do you explain the difference in results?

Before we try to explain what happened in this experiment, let us see how the conditions in the two bottles were different. In the open bottle the molecules of water that escaped into the air could move out of the bottle into the

outside air. In the closed bottle the molecules of water that escaped into the air above the water could not leave the bottle. As more molecules bounced out of the water, the air became more crowded with water vapor. Finally a point was reached when the water stopped evaporating.

Why did the water stop evaporating? The reason is that air can hold only a certain amount of water vapor at any temperature. When it contains all of the water vapor it can hold, we say that it is *saturated*. When the air is saturated, no more water vapor is able to evaporate into it.

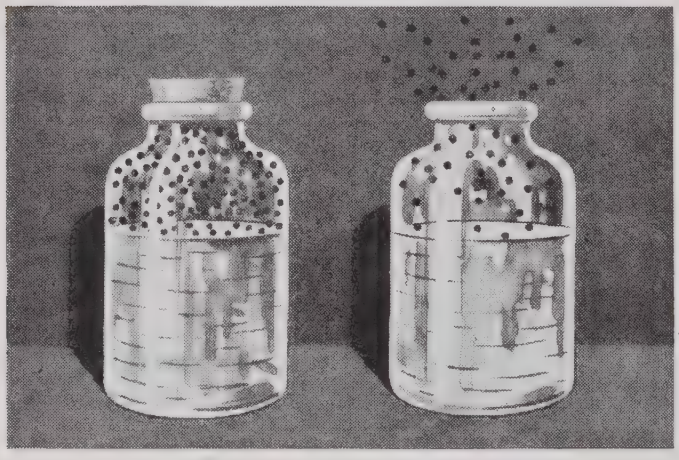


FIG. 238. The action of molecules of water in a closed bottle and in an open bottle

If you pour cold water over the corked bottle used in Experiment 41, drops of moisture will collect on the inside of the bottle. Some of the water vapor in the air in the bottle changes back to liquid water, or, as we say, it condenses. How do you explain this? First of all, you know that the air was saturated. When you poured cold water on the bottle, the air in the bottle was cooled. Then some of the water vapor condensed. Why did this happen? The only explanation we can think of is that cold air cannot hold as much water vapor as hot air. And this is true. The hotter the air is, the more water vapor it can hold. Saturated air at 90° F. contains five times as much water vapor as saturated air at 40° F.

If warm air can hold more water vapor than cold air, we should be able to make water vapor condense from air

if the air is cooled enough. Let us see if we can make water vapor condense from the air that is around us.

EXPERIMENT 42. *How Can We Make Water Vapor Condense?* Fill a tin can or cup about three-fourths full of water and crushed ice. Put a thermometer in the mixture and note the temperature at which drops of water begin to collect upon the outside of the vessel. Repeat the experiment on different days and record the temperature at which the drops of water collect on the vessel. (Sometimes salt must be added to lower the temperature of the cup below 32° F.)

This experiment shows that water vapor will condense from the air if the air is cooled enough. If the air contains a great deal of water vapor, a slight amount of cooling will make condensation take place. The drier the air, the more it must be cooled to make the water vapor condense from it.

Let us summarize what you have learned and then see how the facts help you to explain changes in weather. Water is evaporating from the surface of bodies of water, from fields, and from other moist surfaces so long as the air is not saturated. The warmer the air is, the more water vapor it can hold, and the faster water evaporates into it. When air is cooled, its capacity to hold water and to take up water is decreased. If air is cooled enough, it finally reaches its saturation point, or *dew point*. Then no more water will evaporate into it. If it is cooled below its dew point, some of the water vapor will condense to liquid water.

Now, how does the direction of the wind affect the moisture content of the air? A wind that blows from the south toward the north is blowing from a warm place to a cooler place. What is happening to its capacity to hold water vapor? Is it decreasing or increasing? Since the air

is getting cooler, you know that its capacity to hold water vapor is decreasing. If it is cooled enough, condensation takes place, and we have rain, snow, or fog. Sometimes, as you have learned, the air moves upward. As it moves upward, it is cooled. Rising currents of air thus may also bring about condensation of water vapor.

What happens when winds blow from the north? As the air moves south, it is warmed; therefore it can hold more water vapor. Under such conditions the clouds disappear, and the weather turns fair. A similar thing happens when air moves downward. It is warmer near the earth; so the descending air is warmed, and it can take up more water vapor.

From what you have learned, you now can see that rain or other forms of precipitation are likely to take place if the wind blows in such a direction that the air is cooled. The more humid the air is, the greater the possibility of rain, because humid air needs to be cooled only a little to become saturated. Fair weather will come if the wind blows in such a direction that the air is warmed. In Problem 2 you will see how these conditions are brought about.

HOW ARE DIFFERENT KINDS OF MOISTURE FALL PRODUCED? Sometimes when you go out-of-doors early in the morning, you find that the grass is wet with dew, or that the ground is covered with a white blanket of frost. At other times the ground is quite dry; there is neither dew nor frost. You have also had the experience of seeing moisture come out of the sky in three different forms—rain, snow, and hail.

Before you read the explanations of how dew, frost, rain, hail, and snow are formed, try to remember what the weather was like when you saw these different forms

FIG. 239. Where do you think dew and frost come from?

of moisture coming from the air. There is a certain set of conditions necessary to produce each kind of moisture. What are these conditions?

During the day as the earth is warmed, water evaporates into the air from the moist earth, from plants, and from lakes, rivers, and other bodies of water. When the sun goes down, the earth cools off. The heat is radiated through the air and out into space. The air close to the earth and to objects on the earth is sometimes cooled below its saturation point, or *dew point*. Then moisture forms upon the ground, buildings, and other objects.

Moisture that forms in this manner is called *dew*. Dew is more likely to form on still nights than upon windy nights. If the wind is blowing, the cold air near the ground is mixed with the warmer air; therefore the air near the ground is not cooled below its saturation point. If the temperature at which the saturation point is reached is below freezing, moisture will come out of the air in the form of *frost* (Figure 239). Frost is not frozen dew. The water vapor in the air changes directly to a solid (frost) as it separates from the air.

If you have ever climbed a high mountain or have ridden in an airplane, you may have had the experience of passing through a cloud. If you have not done this,

FIG. 240. Cirrus clouds are sometimes called "mare's-tail" clouds.

you surely have walked or driven through a *fog*. Actually, a fog is just a cloud that is close to the ground. When the temperature of a rather thick layer of air near the earth falls below the saturation point, a fog is formed. The water vapor condenses on dust particles and forms tiny drops of moisture. These drops float in the air. There are so many of these tiny droplets floating in the air that the air looks white. Sometimes the drops get large enough so that we can see them.

Clouds are formed in the same way as fog except that they are in the air above us. The air may be cooled in two ways to cause the water vapor to change into the droplets that make clouds. Warm air that contains much moisture may be blown into a cool region. Here it will be cooled below its saturation point. Or warm air may be forced upward, where it will become cooler, thus causing the water vapor in it to condense.

Have you ever watched clouds change shape? Perhaps you have imagined that they looked like mountains, trees, or animals? What are the names of some of these different kinds of clouds that we see in the sky? There are three types of clouds that are very easy to recognize. One kind is made of very tiny crystals of ice and always looks white.

FIG. 241. Stratus clouds are layer-like clouds.

These clouds are called *cirrus* clouds, and they are the highest ones in the sky. They form at an average height of six miles, but sometimes they are as far as nine miles above the earth. "Cirrus" means tufted, thread-like, or feather-like, and these words well describe the appearance of cirrus clouds.

When a rainy period of weather is coming, cirrus clouds are seen first. Thus we say that mare's-tail clouds usually mean rain, especially if the sky is not bright blue above them. Figure 240 will give you an idea of how some cirrus clouds look.

Have you ever seen a smooth gray sky just before a snowfall? The clouds in such a sky are typical *stratus* clouds. The word "stratus" means "layer." Stratus clouds are one of the commonest kinds. They are always smooth gray and usually hide the moon or the sun. Stratus clouds may be as low as 400 feet, but they usually form at average heights of about 2100 feet.

Sometimes on a hot summer day you see "thunderheads" towering into the sky. These clouds are caused by convection currents. Warm moist air is forced upward by cool air moving in under it. The rising warm air soon

FIG. 242. Cumulus clouds are the dome-shaped clouds that we often see in summer.

reaches the place where it becomes cooled to the saturation point. There it begins to condense, and we see these towering thunder-heads, or *cumulus* clouds. "Cumulus" means piled up. These clouds have all sorts of interesting shapes. They are the ones that we "see pictures" in. The tops of cumulus clouds average about 6000 feet above the earth, while their bases may be within a few hundred feet of the earth. Of course, there are many other kinds of clouds, but they are all made of combinations of the kinds that you have just studied.

Clouds, as you have seen, consist of tiny droplets of water floating in the air. Sometimes rain falls from the clouds we see, and sometimes it does not. Before rain will fall from a cloud, the droplets of water must get so large that they can no longer float in the air. Let us see how this takes place. If a cloud once formed by the cooling of the air is cooled still further, the air can hold less water vapor; therefore more condensation will take place. Some of the water vapor will condense on the drops of water already present in the cloud. This will make these drops larger. As the air moves, drops of water are brought close

FIG. 243. Nearly every winter some section of the United States has a heavy ice storm that glazes everything over with a beautiful, but destructive, coating of ice.

together. When they touch, they unite and form larger drops of water. In these two ways the droplets that make up the cloud finally get so large that they fall to the ground as rain.

Sometimes raindrops fall into a layer of air near the surface of the earth that is below freezing. When this happens, the drops freeze and fall to the ground as *sleet.* At other times, especially during summer thunder-storms, there are strong upward currents of air. Small bits of ice form in the cold air high above the earth. These particles fall into air that is warmer and are covered with water. Then they are caught by the upward currents and again lifted into the cold upper air, where they freeze again.

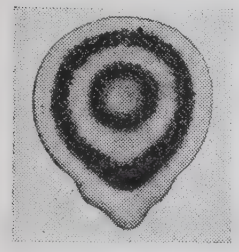


FIG. 244

This process continues until the balls of ice that are formed are too heavy to be held up by air currents. These pieces of ice then fall to the earth as *hail.* Because of the way they are formed, hailstones consist of layers of ice (Figure 244).

Snow, like frost, is formed when the saturation point

of air is below freezing. The water vapor in the air forms tiny particles of ice as it separates from the air. These particles of ice grow and form crystals of snow. Figure 245 shows a photograph of some of the lovely crystals that are formed. The very large flakes that fall in some snowstorms are really made of many crystals that happened to join together as they fell. Like rain, the snow falls when the flakes are so large that they are no longer able to float in the air.

You can now see that while the conditions necessary to produce dew, frost, rain, snow, and hail differ in some ways, in one way they are the same. The air must be cooled below the saturation point before water vapor will condense into liquid water or form solid crystals.

Self-Testing Exercises

1. How long does water continue to evaporate into the air?
2. What happens to saturated air when it is cooled?
3. Which can hold the more water vapor, cold air or warm air? State a proof for your answer.
4. What kind of air will form dew when it is cooled only a little? What kind of air must be cooled a great deal to cause condensation?

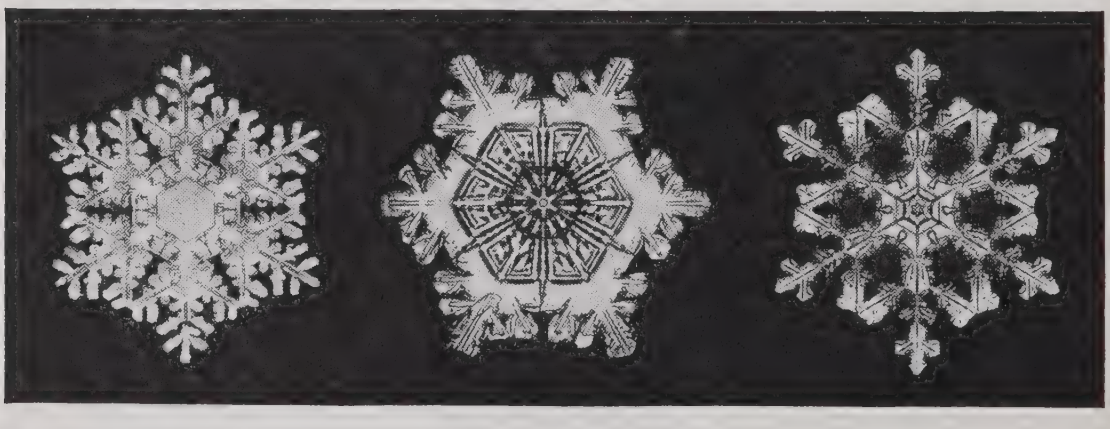


FIG. 245. No two snowflakes ever look exactly alike.

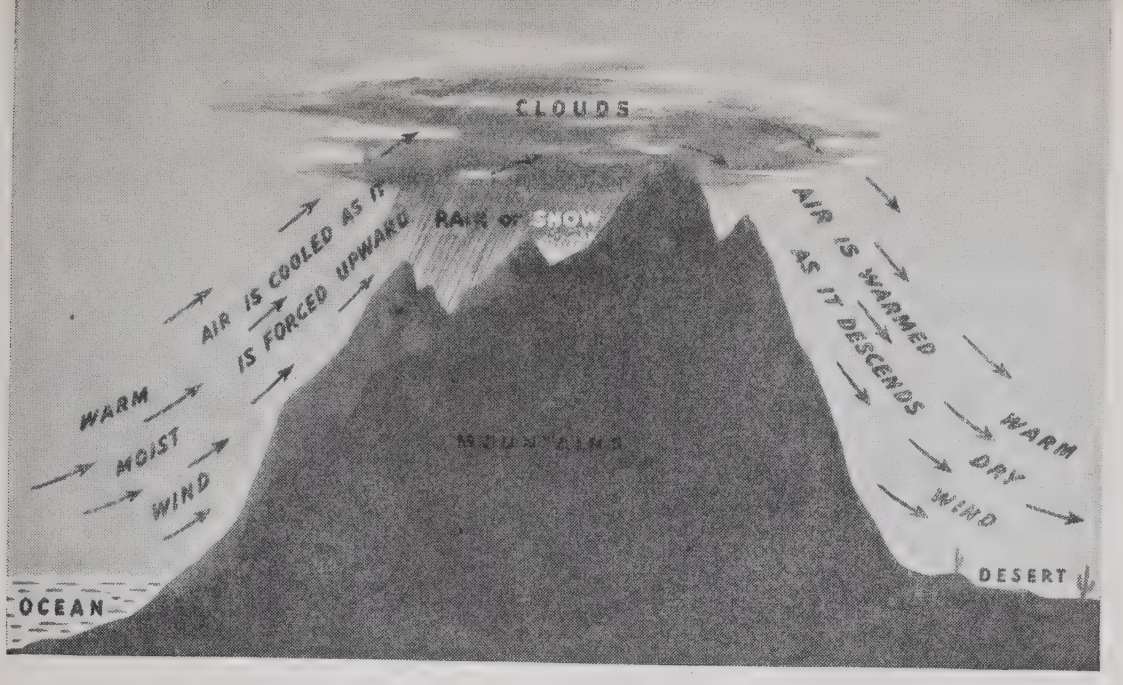


FIG. 246. Diagram for Problem 8

5. What change or changes in the air are likely to bring rain? Fair weather?

6. Explain how each of the following is formed: dew, frost, fog, cloud, sleet, hail, and rain.

Problems to Solve

1. Is it correct to say that dew and frost fall?

2. Get a good book on weather and find what some of the important types of clouds are. Then watch the skies to see if you can actually see any of them. Which kinds of clouds indicate the coming of rain or snow? Which kinds indicate fair weather?

3. Why do we see our breath on cold days and not on warm days?

4. On a cloudy night there is usually no frost. Explain.

5. Why does heating make moist air dry?

6. Icebergs are often surrounded by fog. Explain.

7. When the sun comes out, fogs disappear. Explain.

8. Wind from the Pacific Ocean blows eastward over the Sierra Nevada mountains (Figure 246). There is much rainfall (in the form of both snow and rain) in the mountains and a great dry area on the eastern side of the mountains. Explain these conditions; that is, why is there heavy rainfall in the mountains and little rainfall east of the mountains?

Problem 2:

WHY DOES THE WEATHER CHANGE FROM DAY TO DAY?

WHAT DO WEATHER MAPS SHOW? Let us examine some United States Weather Bureau maps to see what we can discover about the ways in which weather changes. First, what do the different marks tell about the weather? Look for circles marked "HIGH" and "LOW." Around these words you will see a series of black lines. Each line has a number, such as 30.1, 30.2, 30.3. This number shows the pressure in inches of mercury along that line. These lines are called *isobars*. Before the map is made, weather observers all over the country report by telegraph the air pressure and other weather conditions at their stations. Then the weather forecaster draws the map so that each isobar shows the places that have equal pressure.

If you examine the isobars around a "low," you will see that the pressure is the least in the center. For example, the isobar marking the center of the low may be 29.5. The next one from the center will be 29.6, etc. Thus a "low" is a place of lowest air pressure. A "high" is exactly opposite from a "low." The isobars show that the place of highest air pressure is in the center, and the pressure gets less and less as one travels outward from the high.

The temperature at different places is shown by dotted lines called *isotherms*. An isotherm is a line drawn through places that have the same temperature. The figures on the isotherm show degrees of temperature.

Each of the stations at which observations are made is indicated by a circle. The condition of the sky is shown by the following symbols: clear, ○; partly cloudy, ◐; cloudy, ●; rain, ®; snow, Ⓢ. Arrows on the circles show the direction of the wind. Arrows fly with the wind; if an arrow points north, the wind is blowing from the south.

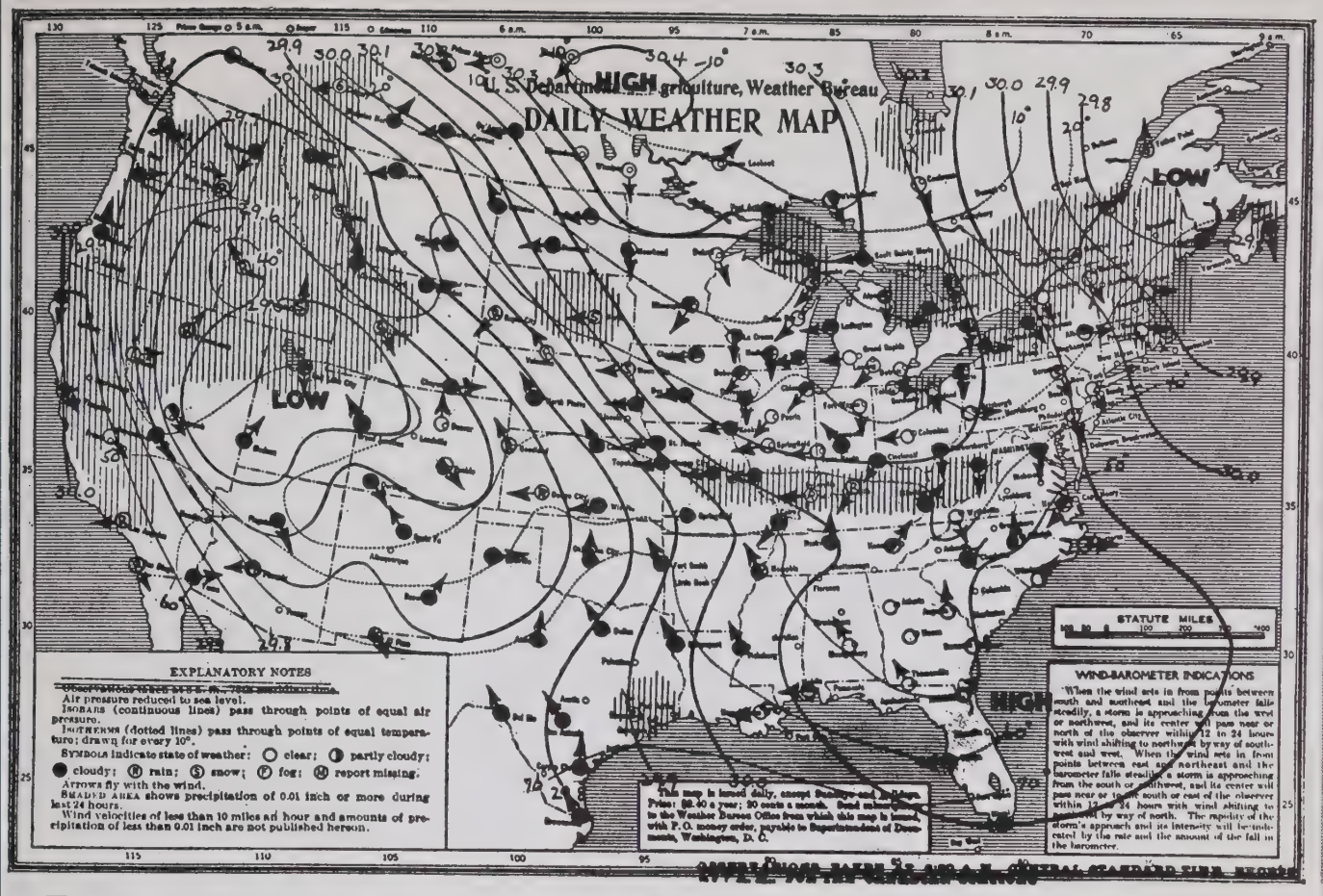
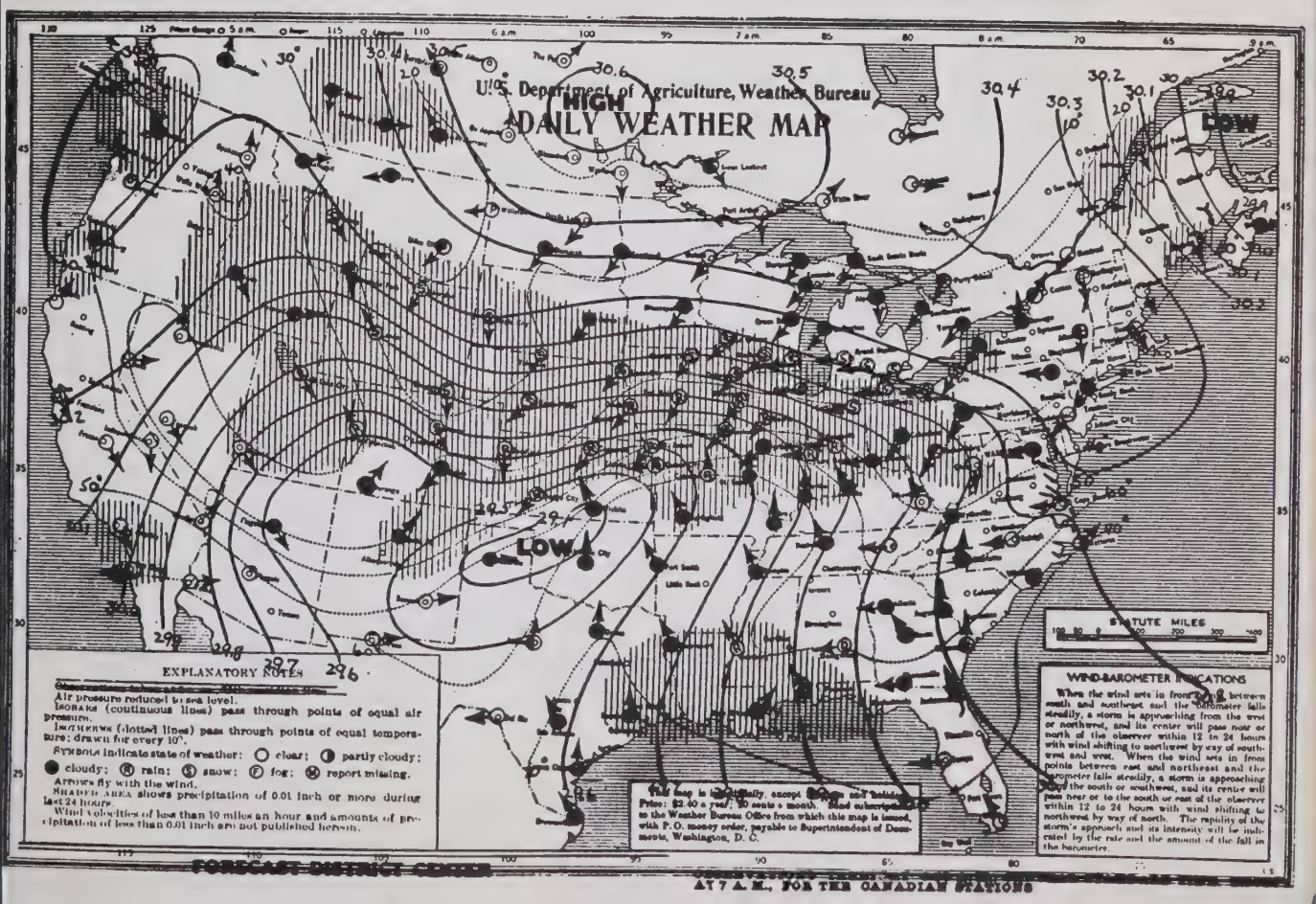

U. S. Department of Agriculture, Weather Bureau
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
EXPLANATORY NOTES
Air pressure reduced to sea level.
Isobars (continuous lines) pass through points of equal air pressure.
Isotherms (dotted lines) pass through points of equal temperature; drawn for every 10°.
Symbols indicate state of weather: ○ clear; ◑ partly cloudy; ● cloudy; (R) rain; (S) snow; (F) fog; (M) report missing.
Arrows fly with the wind.
Shaded area shows precipitation of 0.01 inch or more during last 24 hours.
Wind velocities of less than 10 miles an hour and amounts of precipitation of less than 0.01 inch are not published hereon.
STATUTE MILES
WIND-BAROMETER INDICATIONS
When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.
This map is issued daily, except Sundays and holidays. Price: $2.40 a year; 20 cents a month. Send subscriptions to the Weather Bureau Office from which this map is issued, with P. O. money order, payable to Superintendent of Documents, Washington, D. C.

FIG. 247. Which lines on this daily weather map are isobars? Which lines are isotherms? Find the regions of high and low pressure.

FIG. 248. This weather map is for one day later than that of Figure 247. Notice the direction in which the "lows" and "highs" have moved since the preceding day.


U. S. Department of Agriculture, Weather Bureau
DAILY WEATHER MAP
HIGH
LOW
LOW
EXPLANATORY NOTES
Air pressure reduced to sea level.
Isobars (continuous lines) pass through points of equal air pressure.
Isotherms (dotted lines) pass through points of equal temperature; drawn for every 10°.
Symbols indicate state of weather: ○ clear; ◑ partly cloudy; ● cloudy; (R) rain; (S) snow; (F) fog; (M) report missing.
Arrows fly with the wind.
Shaded area shows precipitation of 0.01 inch or more during last 24 hours.
Wind velocities of less than 10 miles an hour and amounts of precipitation of less than 0.01 inch are not published hereon.
STATUTE MILES
WIND-BAROMETER INDICATIONS
When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.
Price: $2.40 a year; 20 cents a month. Send subscriptions to the Weather Bureau Office from which this map is issued, with P. O. money order, payable to Superintendent of Documents, Washington, D. C.

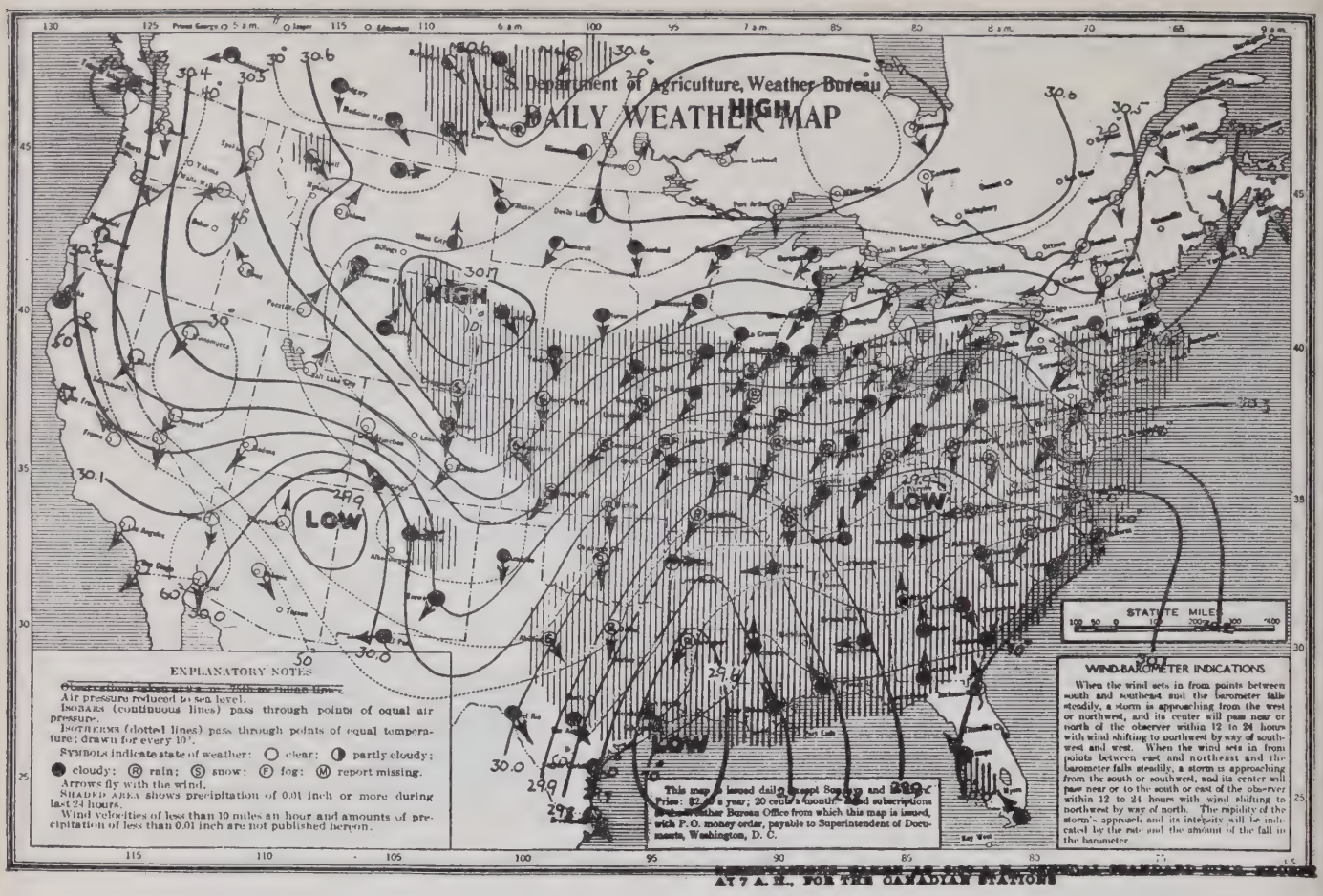

U. S. Department of Agriculture, Weather Bureau
DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
LOW
EXPLANATORY NOTES
Air pressure reduced to sea level.
ISOBARS (continuous lines) pass through points of equal air pressure.
ISOTHERMS (dotted lines) pass through points of equal temperature; drawn for every 10°.
SYMBOLS indicate state of weather: ○ clear; ◑ partly cloudy; ● cloudy; Ⓡ rain; Ⓢ snow; Ⓕ fog; Ⓜ report missing.
Arrows fly with the wind.
SHADED AREA shows precipitation of 0.01 inch or more during last 24 hours.
Wind velocities of less than 10 miles an hour and amounts of precipitation of less than 0.01 inch are not published hereon.
STATUTE MILES
WIND-BAROMETER INDICATIONS
When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.
AT 7 A. M., FOR THE CANADIAN STATIONS

FIG. 249. This weather map is for the day following that of Figure 248. Where are the "lows" and "highs" now?

Now let us see if we can find any difference between the weather in a "high" and in a "low." Look at the circles showing the condition of the sky at different places. Is the weather fair or stormy in places of low pressure? In places of high pressure? Really to answer this question scientifically you would need a large number of maps, because the weather on one day may not be typical of what usually happens. If you had a large number of maps, you would find that the weather in regions of low pressure is usually cloudy, with rain or snow, while the weather in regions of high pressure is usually fair.

Now look at the isotherms. Is it warmer or cooler in regions of low pressure than in regions of high pressure? Here again you would need many maps to answer this question intelligently. An analysis of a large number of maps shows that the temperature is warmer in regions of low pressure than in regions of high pressure. This, of

course, is what you would expect. The pressure is lower in regions of low pressure because the air is warmer than in the areas surrounding it. Now we are ready to see what the weather maps show about changes from day to day.

Figures 247, 248, and 249 show weather maps for three successive days. The regions of high pressure and low pressure have moved across the country. Now you can see why weather conditions will change. Regions of low pressure bring clouds, with rain or snow. If they move across the country, the rains will also move across the country. Regions of high pressure bring fair weather, and, as they move across the country, places in their paths will have a change of weather. Changes in weather conditions are thus the result of the movement of "highs" and "lows" across the country.

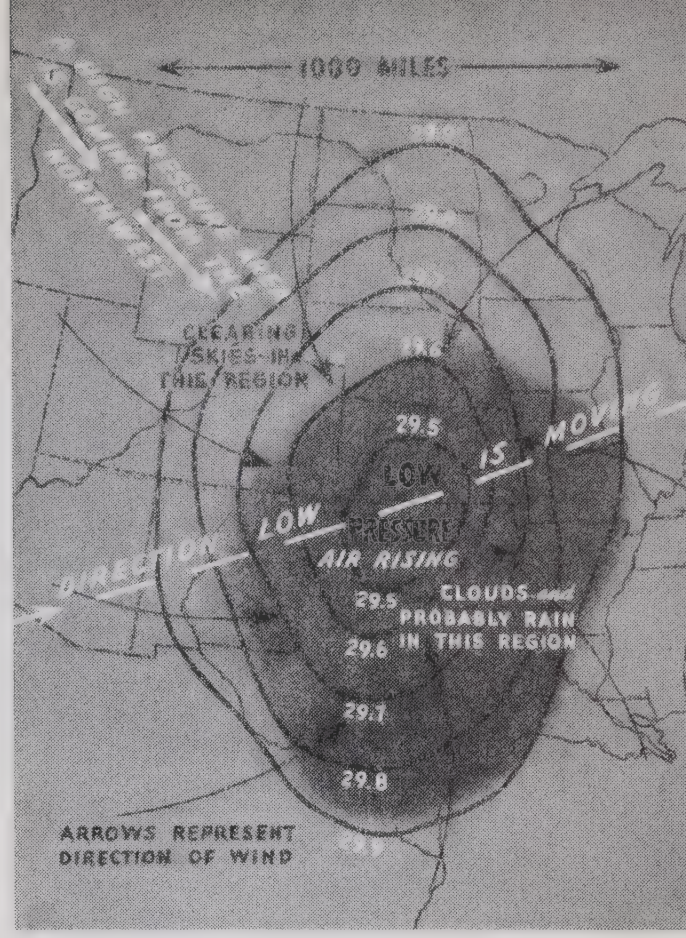


FIG. 250. This diagram explains the weather conditions in a "low." Near the center of the "low" the air is moving upward. As the air is cooled, part of the water vapor it contains is condensed into clouds, causing rain or snow.

WHY DO REGIONS OF LOW PRESSURE BRING CLOUDS AND RAIN? Let us see what is happening to the air in a region of low pressure. Since the air pressure is less in the center of a low than in the surrounding areas, the air will be pushed upward in the center by the heavier air that surrounds it. As the air rises, it is cooled; therefore condensation is more likely to take place.

Figure 250 shows the direction of the winds around a

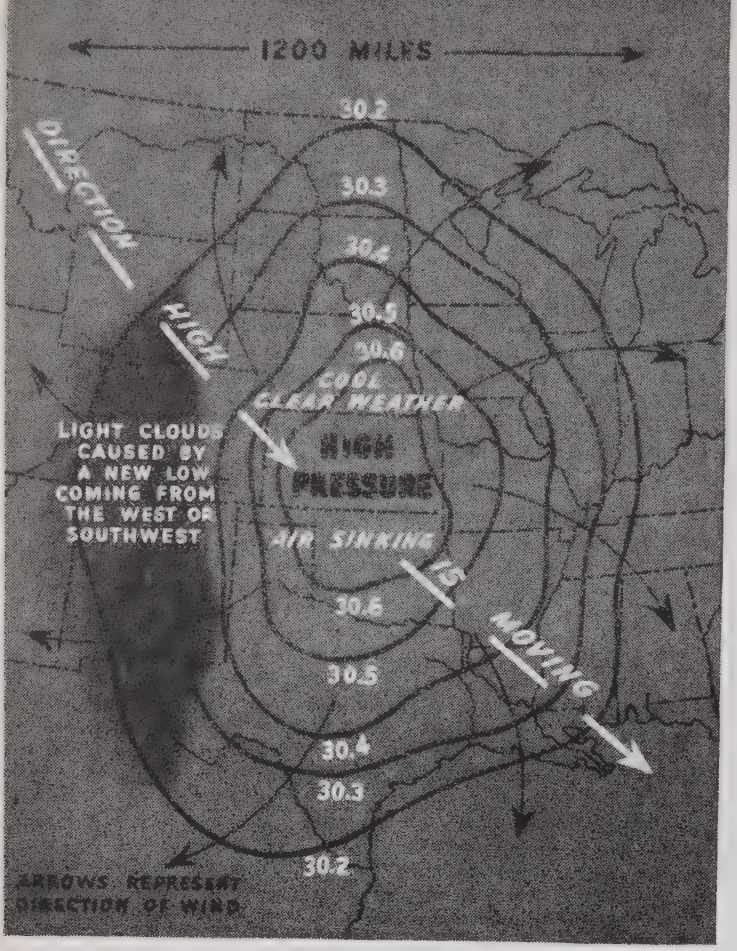


FIG. 251. This diagram explains the weather conditions in a "high." Near the center of the "high" the air is moving downward. As the air is warmed, it takes up more water vapor. Clouds do not form, and the weather is clear.

region of low pressure. You see that the winds spiral in toward the center. You might expect that the winds would blow directly toward the center. If the earth were not turning on its axis, the air would move in directly toward the center. But since the earth is turning from west to east, the air blows in a spiral toward the center.

The drawing also shows that the winds on the eastern side of the "low" bring air from the south. The warm air from the south contains water vapor that it picked up from the Gulf of Mexico and the Atlantic Ocean. As this air moves north and finally upward in the center of the "low," it is cooled below its saturation point, and rain or snow falls.

WHY DO REGIONS OF HIGH PRESSURE BRING FAIR WEATHER? High-pressure areas, or "highs," may be thought of as just the opposite of "lows." In the center of a high-pressure area the heavier cooler air is descending (Figure 251). As the air moves downward toward the earth, it becomes warmer; therefore it can take up more water. Of course, when the air is taking up water from the earth, evaporation is taking place instead of condensation. Therefore rain clouds cannot form. When a "high" is approaching, the weather thus turns cooler, and it becomes fair again.

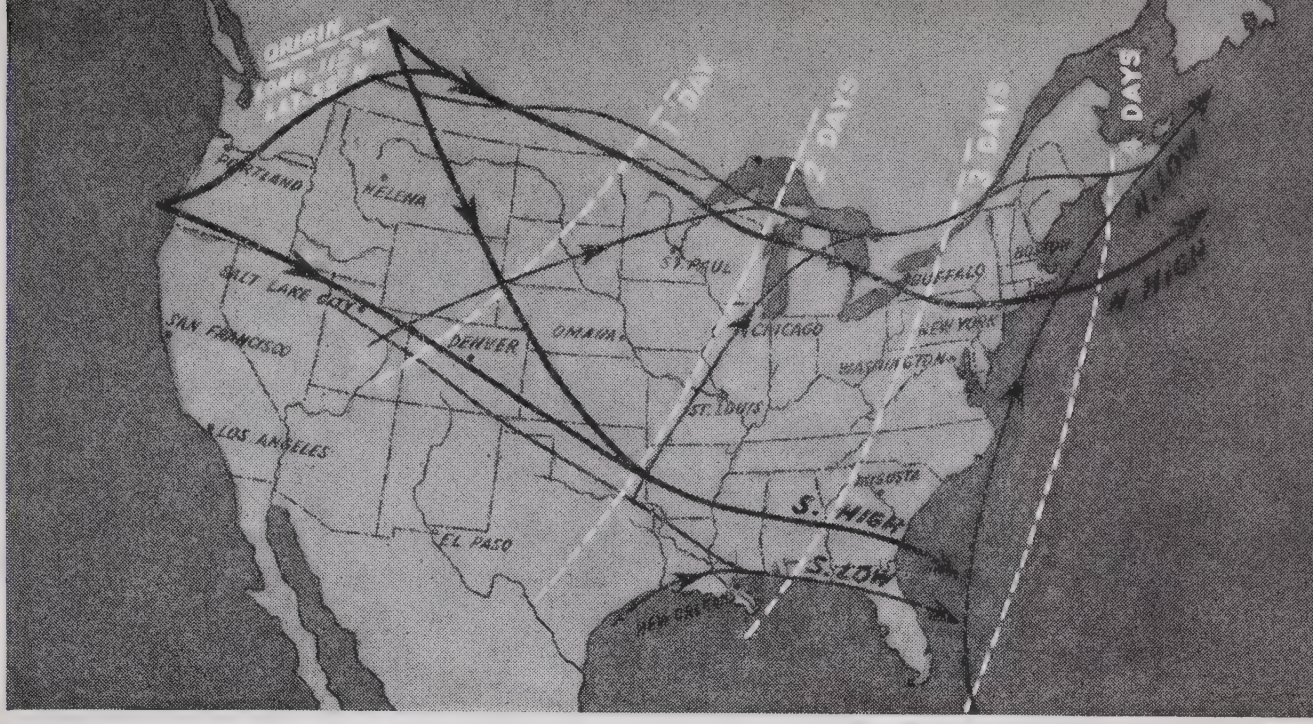


FIG. 252. The general direction of the winds in the United States is from west to east. The heavy lines show the usual paths of the "highs." The lighter lines indicate the paths of the "lows." The average speed of these regions is shown by the broken lines marked 1 day, 2 days, etc.

HOW DO THE "HIGHS" AND "LOWS" MOVE ACROSS OUR COUNTRY? Ever since the Weather Bureau was established in our country in the year 1871, records have been kept of the movement of the "highs" and "lows." From the records the Weather Bureau has been able to construct a map that shows their probable movement. Figure 252 shows how the "highs" and "lows" move across the country. This map is based upon the usual paths.

Sometimes the path and speed of a "high" or a "low" are different from the usual course and speed. When this happens, the weather-man often makes a false prediction. Predicting weather, as you will see in the next problem, is largely a matter of telling how the "highs" and "lows" will move during the next forty-eight hours.

Self-Testing Exercises

1. Suppose that you are teaching someone how to read a weather map. What would you tell him?

2. What kind of weather usually occurs in a "low"? Explain why.

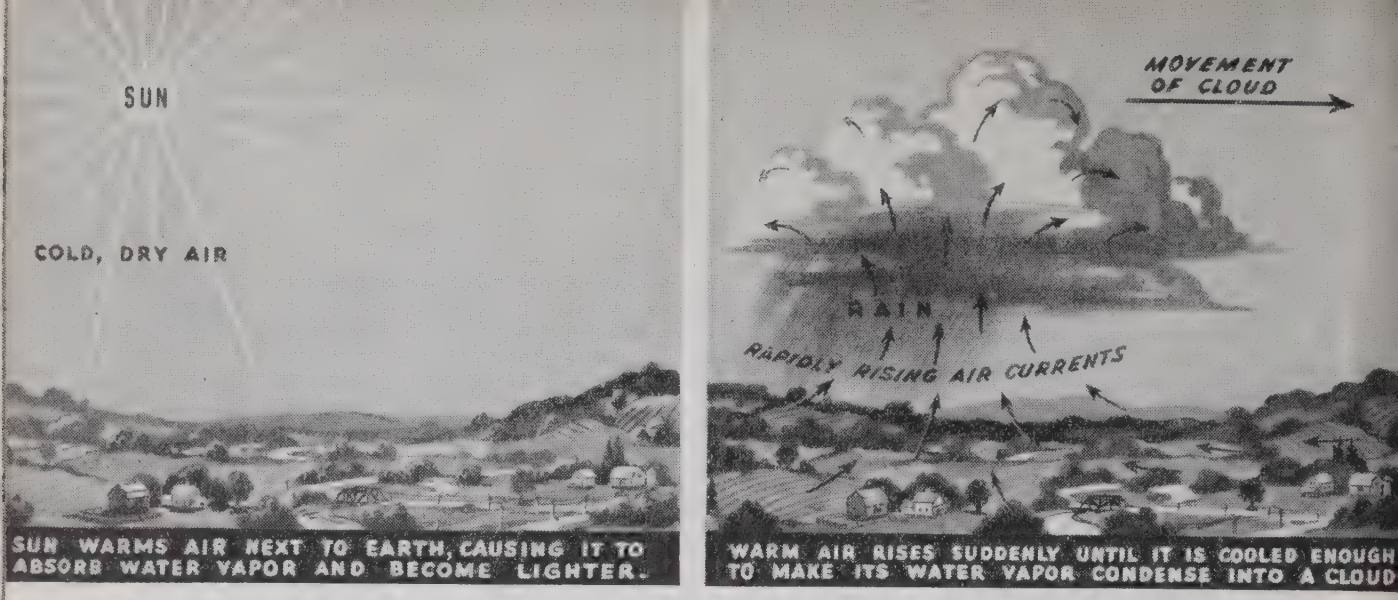

SUN
COLD, DRY AIR
SUN WARMS AIR NEXT TO EARTH, CAUSING IT TO ABSORB WATER VAPOR AND BECOME LIGHTER.
MOVEMENT OF CLOUD
RAIN
RAPIDLY RISING AIR CURRENTS
WARM AIR RISES SUDDENLY UNTIL IT IS COOLED ENOUGH TO MAKE ITS WATER VAPOR CONDENSE INTO A CLOUD

FIG. 253. How a local thunder-storm is caused

3. What kind of weather usually occurs in a region of high pressure? Explain why.

4. In what parts of the United States do "lows" start? In what directions do they move?

5. Suppose that a region of low pressure is west of you. What will be the direction of the wind at the place where you are?

HOW DO LOCAL STORMS BEHAVE? Regions of low pressure, as you see from the weather map, cover large areas. They may be hundreds of miles in diameter; so, of course, they bring storms over wide areas. There are also storms that are local in character. They affect only a very small area. Thunder-storms are storms of this type.

Think of a thunder-storm that you have seen. How quickly it forms! How the lightning flashes, and how soon the storm is over! The weather was probably fair and warm for several days before, and a few thin cirrus clouds were to be seen. What makes such storms happen? On a warm summer day the land absorbs a great deal of heat. But open spaces, such as fields and bare areas, become much warmer than surrounding grassy and wooded places. The air over these places becomes heated and is forced upward. This air rises until it is cooled enough to make its moisture condense into a cloud. Each towering thunder-head is the top of a huge current of rising, moist air.

FIG. 254. Lightning flashes like these cause an unusual amount of light for a brief moment. When lightning is a long distance off, the individual flashes are not seen. Instead, the whole sky becomes lighted along the horizon.

These cumulus clouds, as you know, have large, rounded tops. The bottoms are flat because rising moisture begins to condense at about the same height in all parts of the current. (See Figure 253.) The clouds become larger, darker, and more towering. Finally the sunlight is shut off, and we become alarmed at the appearance of the sky. Flashes of lightning and rumblings occur. It is thought that drops of water in the rising currents of air somehow produce a charge of electricity upon the cloud. When the charge becomes great enough, a large spark, or lightning flash, leaps to the earth or to another cloud. The sudden expansion of air due to the great heat from the flash is believed to cause the terrifying crash of thunder. When the lightning is some distance away, the sharp crashes of thunder are dulled and are changed to rolling sounds by echoes.

As condensation increases, tiny droplets of water grow larger and run together into drops that are too heavy to stay in the clouds. We feel cool wind, and we can see streaks of rain falling from the clouds. As the clouds move toward us, we feel the first splashes of rain. In a short time we are in the midst of a downpour. When the difference in temperature between the bottom and the top of

FIG. 255. As the tip of a tornado moves along, it causes great destruction, and often death.

a cloud is very great, the up-rushing currents of air are strong enough to produce hail.

Local thunder-storms do not cover large areas, and we are often surprised to find that rain has fallen in one town and not in another that is near by. If a town is on the edge of a local storm area, it may even rain on one side of a street and be dry on the other side. Local storms are different from "lows" in that they cover only small areas instead of extending over distances of hundreds and even thousands of miles.

In spring, when there are great differences in the temperature of the air in the central United States, much more violent storms, known as *tornadoes*, are produced. The cause of tornadoes is not fully understood. But we do know that when tornadoes occur, slender currents of air rise with a violent whirling motion. The centrifugal force of these currents throws the air away from their centers. This makes the pressure very low in the center of a tornado. We may recognize such storms by their funnel-shaped clouds that reach to the earth. Fortunately, the tip that touches the ground is small and covers only a small area.

There are two great sources of danger from tornadoes: The winds may reach a speed of several hundred miles per hour, and the suddenly lowered pressure upon the outside of buildings may cause them to burst because of the greater pressure inside them. Luckily these storms do not last long. The rain that often follows is formed by condensation in the tornado. Tornadoes over oceans and seas are known as *waterspouts*. Scientists believe that they pick up little, if any, water.

Great, violent storms, intermediate between the "lows" and the tornadoes, occur in tropical regions. They are called *hurricanes* or *typhoons*.

Self-Testing Exercises

1. Describe a local thunder-storm that you have seen. How was it like the one described in this book?

FIG. 256. Sometimes hurricanes extend as far north as the United States and pass along the eastern and southern coasts of our country, causing great property loss along the coast. After the hurricane of September, 1938, had passed, there were strange scenes, like this one of the motorboat at rest in the yard of a home. The terrific wind had pushed the ocean waters far inland.

2. What kind of air movement usually causes a thunder-storm?

3. Why does hail sometimes accompany thunder-storms?

4. At what seasons of the year are thunder-storms most likely to occur? Why?

Problems to Solve

1. Read descriptions of tornadoes, waterspouts, hurricanes, and typhoons in some good book on weather. How are these storms caused? How are they alike? How do they differ?

2. Read to find more about lightning. Be ready to make a report to the class.

3. What do your own observations show about the condition of the weather when the barometer reading is highest? When it is lowest? To solve this problem study your records for Introductory Exercise 8, page 308.

4. Scientists have found that sound travels about 1100 feet per second. During the next thunder-storm count the number of seconds between a flash of lightning and the time when you hear the thunder. Multiply this number of seconds by 1100, and you will know about how far away the lightning was.

Problem 3:
HOW ARE WEATHER FORECASTS MADE?

WHAT ARE THE CHIEF INSTRUMENTS USED IN WEATHER FORECASTING? Wouldn't you like to visit a weather station and see how the scientists there really find out about weather? Perhaps you have visited such a station. If so, you saw many kinds of maps and charts and many recording instruments. The "weather-men" did not even have to go outside to read the records from most of their instruments, for dials and records inside the building show what is happening outside. What kinds of weather-recording devices do weather forecasters need, and how do the men use their information to foretell weather?

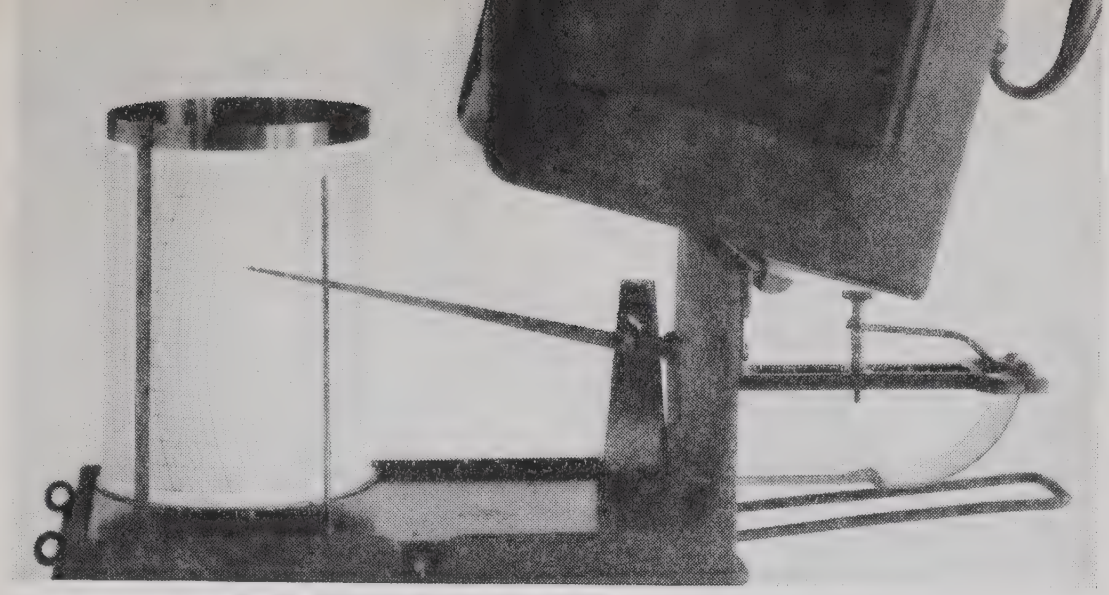


FIG. 257. By means of thermographs, continuous records of the variations of temperature are kept at practically all weather stations.

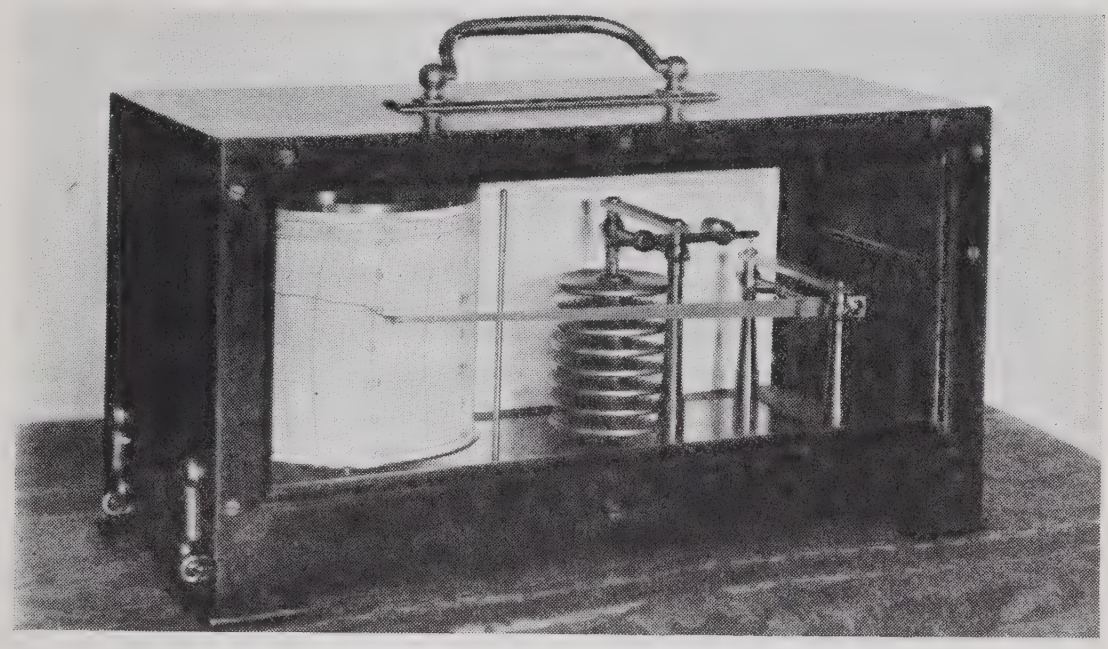


FIG. 258. A recording barometer, or barograph

One of the first instruments you would expect to find in a weather bureau is an accurate thermometer. Each station has one or more of these. There is also a kind of thermometer that shows the lowest temperature in twenty-four hours and one that shows the highest temperature. Each weather station also has a *thermograph*. This instrument records the temperature of the air continuously for periods of a week or longer.

The thermometer of a thermograph is a metal coil that unrolls slightly when the air becomes warmer and closes

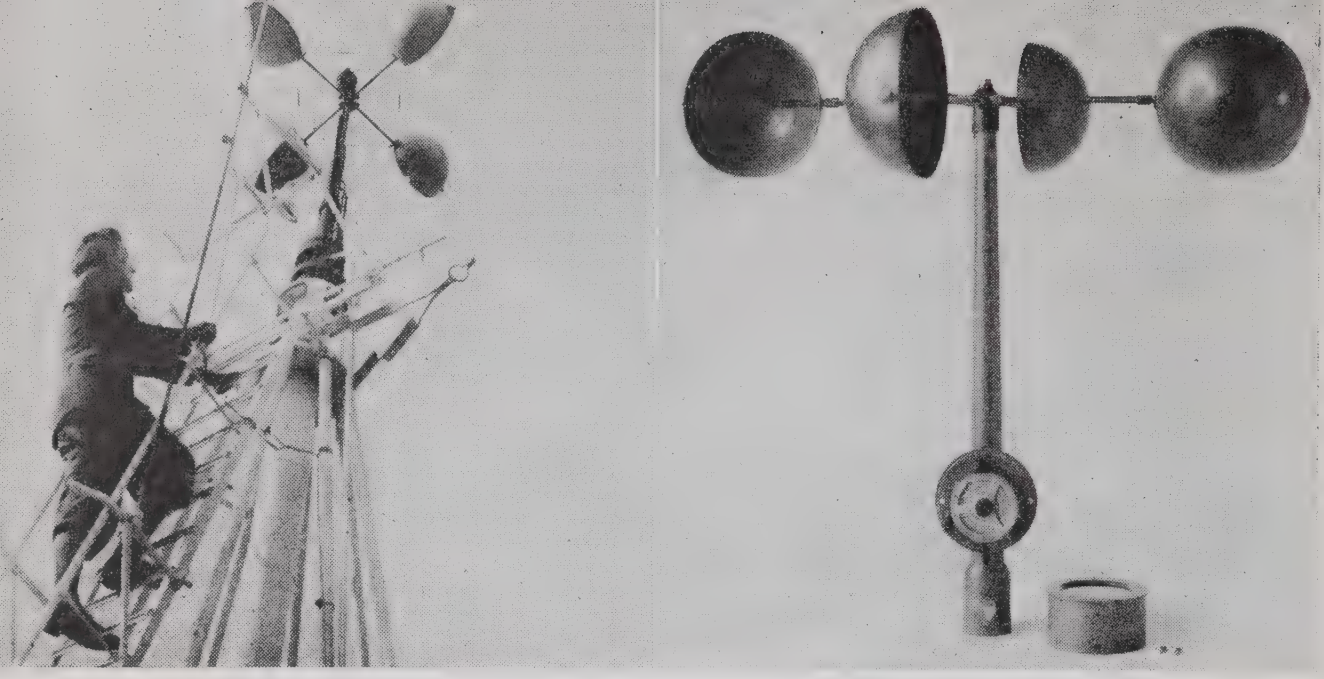


FIG. 259. An anemometer has several metal cups set so as to turn the vertical axis to which they are attached. The anemometer is connected by electric wires to the office below where the number of revolutions per minute is recorded.

when the air becomes cooler. (Why does it do this?) These changes in the coil raise and lower a long bar that carries a kind of a fountain-pen. The pen makes a mark on a sheet of graph paper wound about a drum. The drum is turned at the correct speed by a clock, so that the pen makes a graph of the temperature record hour by hour for a week.

In the weather observatory you would find at least two barometers. The official readings are made with a mercury barometer. (See page 103.) The Weather Bureau also uses a recording barometer, or *barograph* (Figure 258), that makes a graph of the air pressure. The graph gives a continuous record of changes in air pressure throughout the day.

Weather forecasters must know the direction of the wind and how hard it is blowing. An electric-recording *wind vane* that gives the direction of the wind once each minute is used for this purpose. An *anemometer* tells how hard the wind is blowing (Figure 259). Recording devices attached to the anemometer show the velocity of the wind in miles per hour.

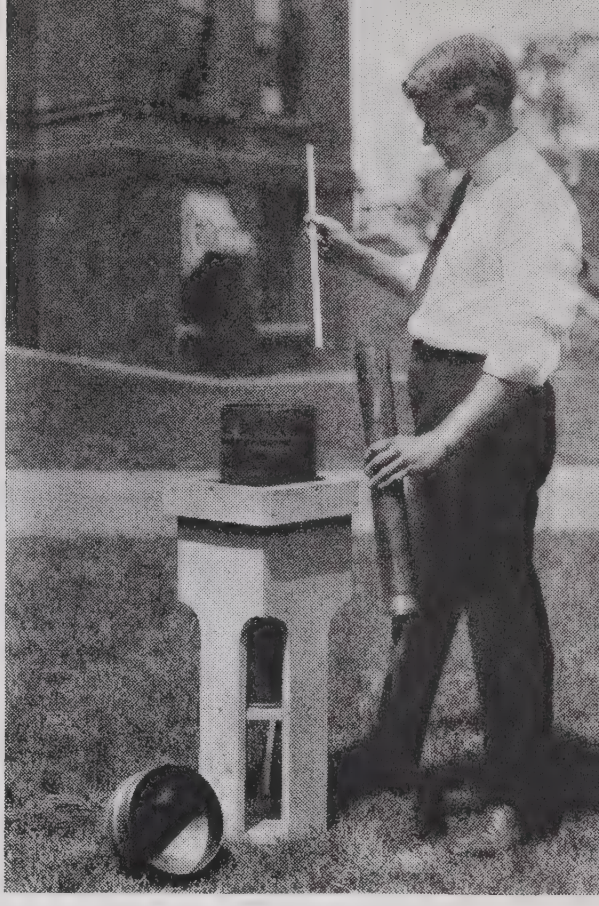


FIG. 260. Measuring the depth of rain in the tube of a rain gauge

The amount of rain that falls is measured by a *rain gauge*. A rain gauge is a galvanized can about eight inches in diameter and twenty inches high. The "weatherman" measures the depth of the rain in the tube much as a garageman uses a ruler-like stick to measure how much oil is in an automobile.

The depth of snowfall must be measured, too. This is done by pushing a measuring rod, much like a ruler, straight down into the snow. Of course, a place has to be selected where the depth of the snow has not been changed by drifting. To keep an accurate record of the total amount of water falling on the earth, a weather observer needs to know how much water falls in the form of snow. To measure this he has a straight-sided can called a *snow gauge*. After a snow-storm the gauge is taken inside, and the snow is melted. Then it is poured into the rain gauge and measured as rain is measured. Scientists have learned that it takes an average of ten inches of snow to equal an inch of rain.

In addition to these instruments each station has a wet-and-dry-bulb thermometer for measuring the humidity. Some well-equipped observatories have a number of other, more complicated instruments. All of these instruments are located in places where their readings will not be affected by buildings, trees, or other objects that might make them inaccurate.

FIG. 261. These men are sending up a pilot balloon. The balloon is made of rubber and is inflated with hydrogen to about 28 inches in diameter.

If the station you visit is a large one, you may be fortunate enough to see the men sending up *pilot balloons*. These balloons are sent up four times daily. By watching their rate of rise and the direction they are blown by the wind, the observer can estimate the direction and velocity of the wind high above the earth.

Some stations send up balloons that carry automatic radio sending-sets. To each radio set is attached an instrument that measures humidity, temperature, and the pressure of the air. As the balloon rises, the radio set sends these measurements to a receiving set in the weather station. When the balloon gets so high that it bursts, a parachute brings the instruments safely back to earth.

Self-Testing Exercise

Make a list of at least six kinds of information that weather forecasters get from their instruments. Opposite each, write the name of the instrument or instruments used to collect it.

Problems to Solve

1. Make a wind vane.

2. Learn from reference books how the different weather instruments work. Find some kinds not mentioned in this book.

3. If you can obtain a thermograph record for one or two weeks, study it to find what time of day is warmest and what time is coolest.

4. Perhaps you have made a wind vane of a straight wood arrow. Find why the Weather Bureau uses a wind vane with a

double tail, with the tails joining at an angle of twenty-two degrees. Draw a diagram to help you.

5. Find out exactly how a wet-and-dry bulb thermometer tells the humidity of the air.

6. You can make a barometer very easily. Get a glass tube about three feet long. Close one end of the tube by heating it in a flame. Fill it with mercury. Place a finger over the open end of the tube and turn it upside down in a small dish of mercury. Tie a yardstick to the tube and fasten them to a ring stand, as shown in Figure 262.

From day to day measure the height of the mercury in the tube above the level of the mercury in the dish.

HOW ARE WEATHER MAPS MADE? Probably the greatest weather system in the world is the United States Weather Bureau. The main office is in Washington, D.C., with other forecast centers in San Francisco, Denver, New Orleans, and Chicago. There are also about three hundred substations in the United States, Alaska, the West Indies, and in other possessions. Each state has at least one substation, and sometimes several, depending upon the size and kinds of land and water areas in the state.

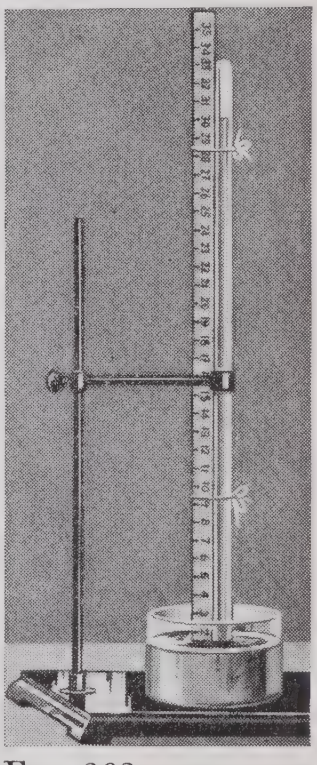


FIG. 262

Weather maps, like those in Figures 247, 248, and 249, are made at each forecast center every morning. Then the maps are used to make the forecasts that you read in the newspapers and hear on the radio. To make a weather map, a forecast center must know these things: the pressure of the air; the temperature of the air at the time the report is given, and the highest and

FIG. 263. From the forecast map room of the Weather Bureau, weather reports received from over 300 regular observing stations in the U. S., Alaska, and the West Indies are charted on the maps for study and interpretation. Within a few hours after this, the maps are sent to over 1600 distributing points.

lowest temperatures for the past twenty-four hours; the direction and velocity of the wind; the general weather condition (clear, partly-cloudy, cloudy, fog, snow, rain); and how much rain fell in the twenty-four hours before the report.

A new weather map is made each morning, for the Weather Bureau cannot make forecasts over long periods of time, as almanacs pretend to do by guesswork. All weather observations must be taken at the same time and reported to the centers where the maps are to be made. Reports are made at 8:00 A.M. Eastern Standard Time in the eastern states, 7:00 A.M. Central Time in the central states, 6:00 A.M. Mountain Time in the Rocky Mountain region, and 5:00 A.M. in the Pacific States (see Unit 1).

As this necessary information is received from the smaller stations, the forecaster records it on a large map of the United States. He locates the places of high pressure and of low pressure and draws isobars to connect points of equal pressure. Through points of equal temper-

ature he draws in the isotherms. Now he has the information all spread out before him so that he can study it.

How is a weather forecast made? As you already know, the weather at any place is largely a matter of whether it is in a region of high pressure or in a region of low pressure. The map shows the forecaster where the "highs" and "lows" were at the time the information was collected. To predict the weather, the forecaster must decide in which direction the "highs" and "lows" probably will move and how fast they probably will travel. He can predict the direction because the records that have been collected for years show what paths are usually followed by the "highs" and "lows" (Figure 252). Of course, there are often unusual conditions which he must also take into account.

The speed of movement of the "high" or of the "low" is also predicted upon the basis of records that have been kept. For example, suppose that the weather map shows a "low" entering the northwest corner of the United States. Figure 252 shows the path it will probably take. In about 48 hours its front will reach the western shore of Lake Michigan. So, for the region around Lake Michigan rain is forecast in about 48 hours. You will see from the map that it takes about four days for a "low" or a "high" to travel from west to east across the United States.

Figure 252 shows you that "lows" travel from west to east. Those that originate in the southern part of the United States travel north and east. If you locate (on the map) the place where you live, you can see the direction from which the areas of low pressure come. If you know this, you can tell from the direction of the wind what kind of weather is likely to follow. For example, if you live near Chicago, "lows" may approach from the west or

from the south or southwest. Now look at Figure 250 and see what direction the wind will be if a "low" is approaching from the west. You see that it will be a southeast wind. If the "low" is approaching from the south, there will be a northeast wind. In this region when the wind is blowing from points east, there is likely to be rain.

Of course, local conditions sometimes cause changes in the direction of the wind; thus the wind is not always a safe guide. If you have a barometer, however, you may be certain that the direction of the wind is the result of a low-pressure area on its way toward you. For example, if the wind shifts to the southeast and the barometer falls, a "low" is approaching from the west. If the wind shifts to northeast and the barometer falls, a "low" is approaching from the south.

As the "low" passes, two things will happen: The barometer will rise, and the wind will shift so that it comes from points west or northwest. If, therefore, the barometer begins to rise and the wind shifts to the west, you know that the center of the "low" has passed and that fair and cooler weather probably will follow.

WHY IS THE WORK OF THE WEATHER BUREAU IMPORTANT? The United States Government spends about two million dollars each year upon its weather service. Why should the government spend so much money on the Weather Bureau? Let us examine some of the ways weather forecasting helps people.

Storm warnings are given all along the coasts and on the Great Lakes. These help ships at sea and people who live along coasts to protect themselves against storms. Many stations issue cold-weather warnings in time for fruit growers and truck farmers to light smudge fires in their orchards (Figure 265) and to cover their young, tender

FIG. 264. The captain and the first officer of a trans-continental airplane are going over the weather map with the dispatcher at the airport before they take off on a regular scheduled flight.

plants. The Weather Bureau is worth its cost each year in the number of lives and the amount of property it saves.

Probably one of the most valuable services the Weather Bureau gives is to aviation. Accurate information broadcast regularly to fliers tells them the kinds of weather they will fly into, and forecasts of unfavorable conditions tell pilots when it is not safe to attempt long trips.

In a similar way, long-distance shipping of farm products by truck and rail is aided by a knowledge of approaching weather conditions. And what about yourself? When you are planning a picnic, a long automobile trip, or anything out-of-doors, do you not read the forecast in the daily paper or listen for it over the radio?

Self-Testing Exercises

1. Draw a map upon which you place a circle showing your city. Draw in lines to represent the paths of regions of low pressure near your city. From which direction do they come?

FIG. 265. Fruit growers may protect their trees by adding heat to the air around the trees. They do this by burning a large number of small heaters in the orchards.

2. Suppose that a weather map shows a "low" starting in southern Texas. What weather would you predict for Oklahoma City, Kansas City, and Chicago?

3. What will be the probable direction of the wind if a "low" is approaching your city?

4. What does a barometer do to tell whether a change in wind direction is the result of the approach of a "high" or a "low"?

5. How does the weather map help a forecaster predict the weather?

6. Do you think that it would be safe to predict weather for several weeks ahead? Give a reason for your answer.

7. Is the Weather Bureau worth its cost? Why?

Problems to Solve

1. How many weather stations has your state? Find where they are located. What does the surface of the land and the size of your state have to do with the number of stations?

2. Get a recent weather map and compare the weather where you live with the kind of weather in Alaska on the same day.

3. Without reading it, cover the forecast on a recent weather

FIG. 266. Warnings of heavy snow enable the Highway Departments to get their snow ploughs ready to clear the snow out of the roads as soon as it falls.

map and make a forecast of your own. Then compare it with the forecast made by the weather man.

4. Find how smudge fires protect orchards from frost.

5. How accurate are the forecasts in your locality? Clip the forecasts each day for two weeks or a month. Give the weather man a grade for each day. At the end of the time average all of the grades. Your conclusions will be more accurate if several people do this exercise together.

LOOKING BACK AT UNIT 7

1. Make a list of the different conditions that make up our weather, such as sunshine, etc.

2. Look at a weather map and tell what you need to know in order to make a weather forecast from the map. Write your answers out in complete sentences.

3. Give the meanings of these words:

radiant energy	*"high"*	*"low"*	*humidity*
water vapor	*tornado*	*waterspout*	*cirrus clouds*
saturated air	*thermograph*	*barograph*	*anemometer*
hail	*sleet*	*frost*	*wind*

ADDITIONAL EXERCISES

1. Keep a scrap-book of newspaper clippings of unusual weather conditions. Try to explain what caused these conditions.

2. Find what causes mirages.

3. On some dark night when vivid streaks of lightning are to be seen, set a camera in a window pointing toward the place where lightning flashes are most frequent. Select a spot where street lights will not interfere. Open the shutter of the camera until you see a flash of lightning appear. Close the shutter and have the negative developed. If you were fortunate, you may have secured a good lightning photograph. Do not be discouraged if your first efforts fail, for this kind of photograph is well worth several attempts.

4. Find the difference between zig-zag and sheet lightning.

5. With the help of some of your classmates or your science club set up a weather bureau for your school. You can make most of your weather instruments. (See Pickwell's *Weather*, Chapter 6.) Use blank U. S. Weather Bureau maps and try to issue forecasts of the weather each day.

6. Obtain for your school a daily copy of the official U. S. weather map and keep it posted. Also post all interesting facts about local weather records.

7. Obtain some transparent paper. Place the paper over a weather map. Trace the word "Low" from the map. Then trace the circles representing different weather stations and showing the kind of weather at each station. Repeat this with eight or ten maps. Count the number of stations that show rainy or cloudy weather and the number that show clear weather. What do you find?

8. Repeat Exercise 7 for regions of high pressure.

FIG. 267. It has taken man a long time to learn how the human body works. For thousands of years he did not even know that the blood is pumped through the body in a steady stream by the heart. Aristotle thought that the blood was made by the liver and used up by the body. Other thinkers believed that the blood flowed by itself, fast in some places and slowly in others.

About 300 years ago, William Harvey, an English physician, proved that the blood is pumped in a steady stream throughout the body. In this picture he is showing how the heart is made so that the blood is pumped out of one side of the heart, goes through the body, and flows back into the other side of the heart. When you have studied this unit, you will understand why this was one of the greatest discoveries ever made about the human body.

UNIT EIGHT

UNIT 8

HOW DO OUR BODIES WORK?

INTRODUCTORY EXERCISES

*1. What are the cells of living things? Where in your body can cells be found?

2. Name three important uses of bones in your body.

*3. Name some chemical changes that go on in your body. Of what value to your body is each change that you have named?

4. Name in order the organs through which your food passes while it is being digested.

5. How many kinds of blood tubes do you have in your body? What are they, and how are they different from each other?

6. Why must food be digested?

*7. What kinds of energy does your body need? How does it get the energy it uses?

8. Why does a person's body usually die when his heart stops beating?

9. Why is air necessary to keep a person alive?

10. What is the use of kidneys in the body?

*11. What do you mean when you say that a solid is dissolved? Explain fully, and be sure that you know what *solution* and *soluble* mean.

*12. What is oxidation?

*13. What are the three main classes of food, and what elements are found in each class?

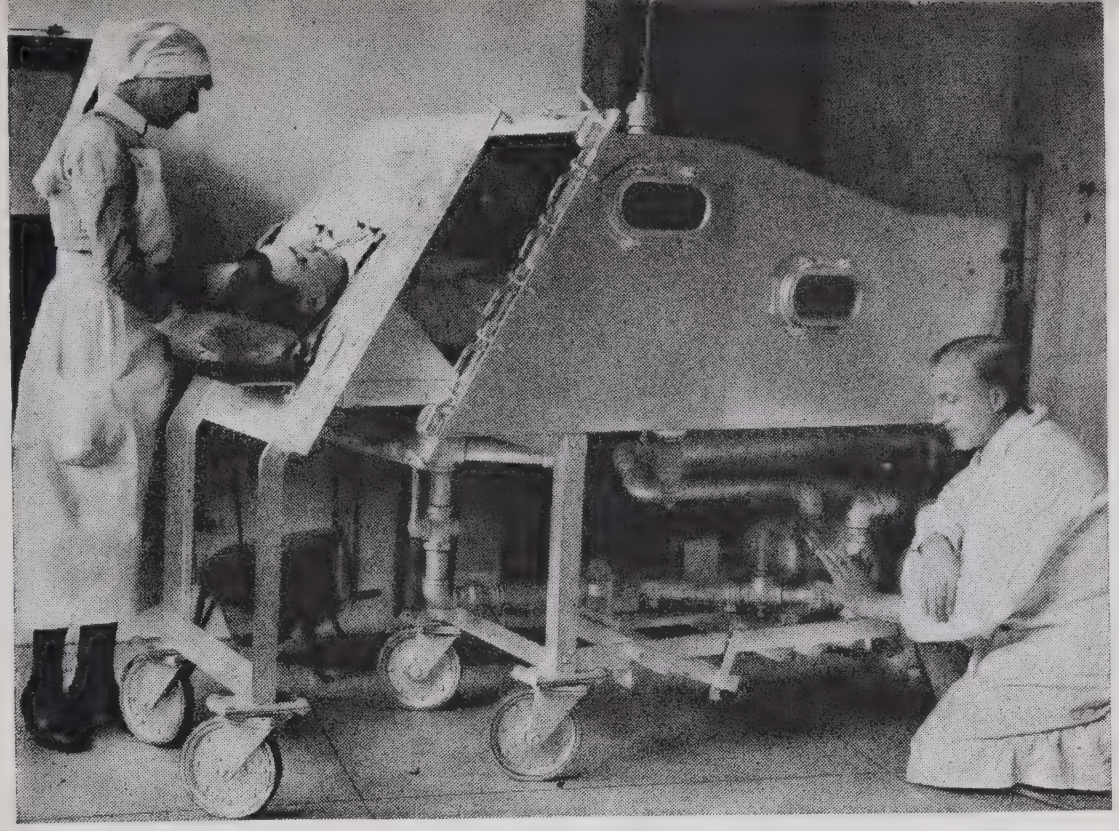


FIG. 268. A machine that helps the human machine. The famous "iron lung," invented only a few years ago, has saved many lives. In certain kinds of diseases the chest muscles become paralyzed. They cannot raise and lower the chest for breathing. In the "iron lung" the air pressure is alternately increased and decreased, which forces the chest to move as it does when a person breathes naturally. In time the chest muscles begin to work again, and the person is saved.

LOOKING AHEAD TO UNIT 8

THE MODERN automobile is an interesting and wonderful machine. Early automobiles so often failed to run that there were many jokes about them. But today the automobile has been so improved that we can drive thousands and thousands of miles with practically no trouble except to see that the car has fuel, oil, and water. Inside each car is an electrical system, an oil system, a water or cooling system, a fuel system, and many other parts. Each system and part is connected to the others, so that they automatically work together to make the car go.

Some day you probably will learn to drive one of these complicated machines. Your father or a teacher will help you learn what each of the different systems does to make the car run, why it starts when you turn a certain gadget

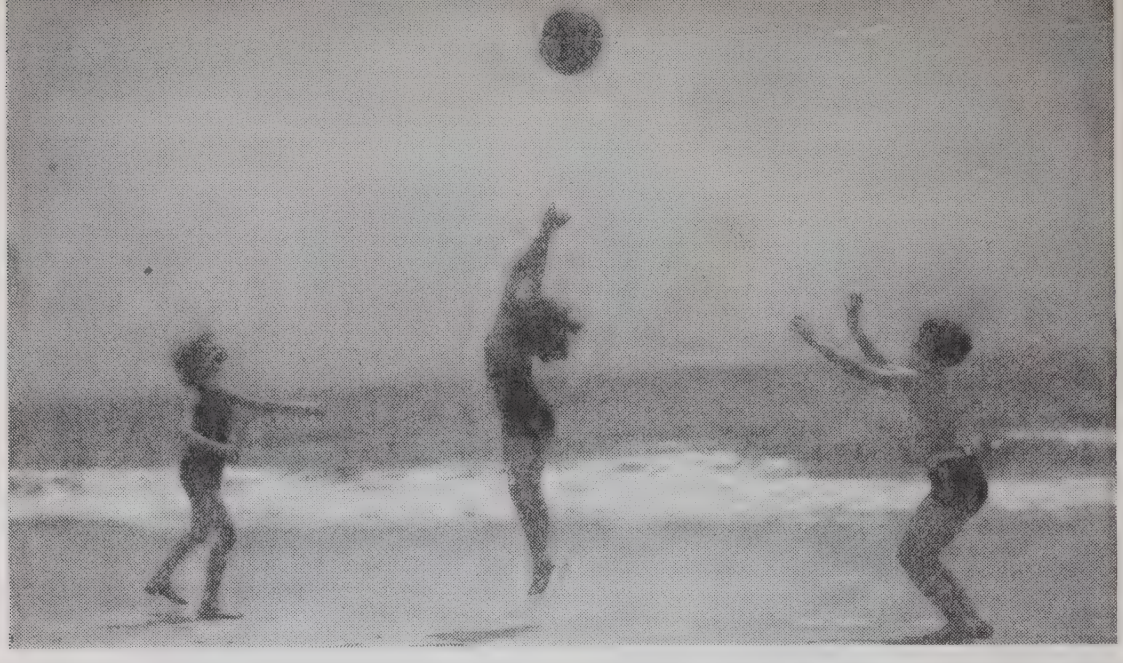


FIG. 269. The human body is the most wonderful machine in the world. It can do things that no other machine can do. Are you intelligent about your body, or do you just run around in it without knowing how it works?

or push that lever and release this one, how it burns gasoline, and why it must have oil and water. Not only will you learn the main things about how the car works, but you will learn the "rules of the road," and the dangers of driving, and how to avoid them. All these things you will learn so that you can drive a car intelligently.

However, you are already "driving" a more complicated and wonderful "machine" than an automobile. This "machine" is your own body. What do you know about how it works? What makes it go? What different systems are found inside it? What does each one do to keep the body running smoothly? What is most liable to go wrong with its machinery, and how can trouble be prevented?

If you do not already know the main things about how your body is put together and how it works, this unit will help you to understand them. The unit will not be able to tell you everything that is worth while for you to know about your body and its health. However, you can find out enough to go on learning by yourself, and some of your later work in science will add to your knowledge. This unit is the foundation for further learning.

Problem 1:

HOW IS THE BODY PUT TOGETHER?

HOW IS THE FRAMEWORK OF THE BODY CONSTRUCTED? Everyone knows that he has bones in his body. Yet the bones of our framework usually give us so little trouble and require so little attention that we know very little about them. There are more than 200 different bones in the human body, all nicely fitted together at the *joints*. If you grow to be a person of average size, all your bones together will weigh about twenty pounds.

By looking at a human skeleton like that in Figure 271, you quickly see that there is a central column of bones to which the ribs and the bones of our arms and legs are attached. This column of bones is the backbone (Figure 270). Each piece of the backbone is called a *vertebra* (plural, *vertebrae*). Each vertebra has several projections to which muscles are attached.

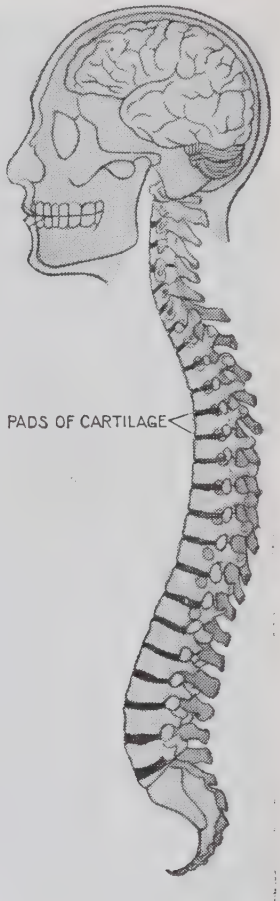


FIG. 270. Backbone and skull

But the backbone is not all bone. Between each vertebra and the next one is a pad of flexible *cartilage*. When we find cartilage in meat, we call it *gristle*. Your nose and ears contain cartilage that gives them shape and holds them up, yet allows them to be flexible. As you walk, the cartilage pads in your backbone absorb the jar of each step, so that very little of it reaches the skull, that is mounted on the upper end of the backbone. Curves in the backbone also absorb some of the shock. These curves help to make the backbone "springy."

At the shoulders there is a set of special bones, called the *shoulder girdle*, to which the arms are attached. The shoulder girdle includes the collar bones and shoulder blades. At the hips is the hip girdle, or *pelvis*, to which the leg bones are attached. In front is the *breastbone*.

This skeleton of yours is a very necessary part of your body. Without it you would be as soft and flabby as an earthworm. It provides the framework upon which the rest of your body is built, and, as you can see, the shape of your body is determined by the shape of your skeleton. Furthermore, certain parts of the skeleton, such as the skull and ribs, protect the delicate parts of your body from injury.

FIG. 271. The human skeleton

You could not move as you do if there were no bones to act as levers to push or pull you around from place to place. The framework of your body is thus quite different from the framework of a house. In a house the parts of the framework are attached rigidly together so that no movement is possible. Your framework is rigid enough to hold your body in shape and flexible enough to allow its parts to move.

Self-Testing Exercises

1. List the main sections or divisions of your body's framework. Begin with the backbone.
2. What are some of the advantages of having cartilage in your skeleton?
3. State three important uses of the skeleton in your body.

HOW ARE OUR BONES JOINED TOGETHER? Some bones of the body, such as those in the head and in the hip girdle, are joined together so that they cannot slip past one another. However, in most other parts of the body our bones can move on one another at the joints.

On first thought, a joint does not seem to be anything unusual. Our machines have joints and bearings where their parts are connected. But the movable joints and bearings in machines are a great problem for engineers. They must move easily, but they must not be loose; they must wear a long time; they must be strong. Joints that can do these things grow in our bodies without attention from us. You will understand joints better if you can study a real one.

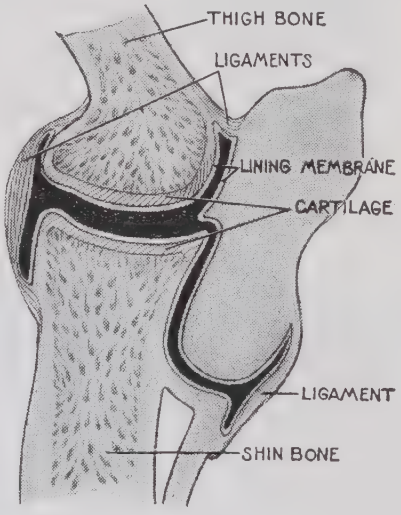


FIG. 272. A typical joint

EXPERIMENT 43. *What Is the Structure of a Joint?* (*a*) From your butcher get a "sheep shank." This is a joint from the front leg of a sheep. Try to bend the joint in every direction. What is the result?

b) Carefully remove the outer coverings of the bones and joint until you come to the tough white bands of tissue, the *ligaments*, that hold the bones together at the joint. Also find the white cords, or *tendons*, that attach the muscles to the bones. See if you can break the ligaments by bending the joint sidewise or backward. How strong are they?

c) Carefully cut away the ligaments on one side of the joint, so that you can see the ends of the bones that rub together. Notice the parts that rub against each other. What kind of covering do they have? Are they dry or moist? How are they lubricated? Look for a lining inside the ligaments that shuts out other materials and keeps the lubricating fluid inside.

If you did Experiment 43 with reasonable care and thoroughness, you have a fair idea of the structure of the movable joints in our bodies. The joint in a sheep shank is a *hinge joint* like those in your knees and fingers; that

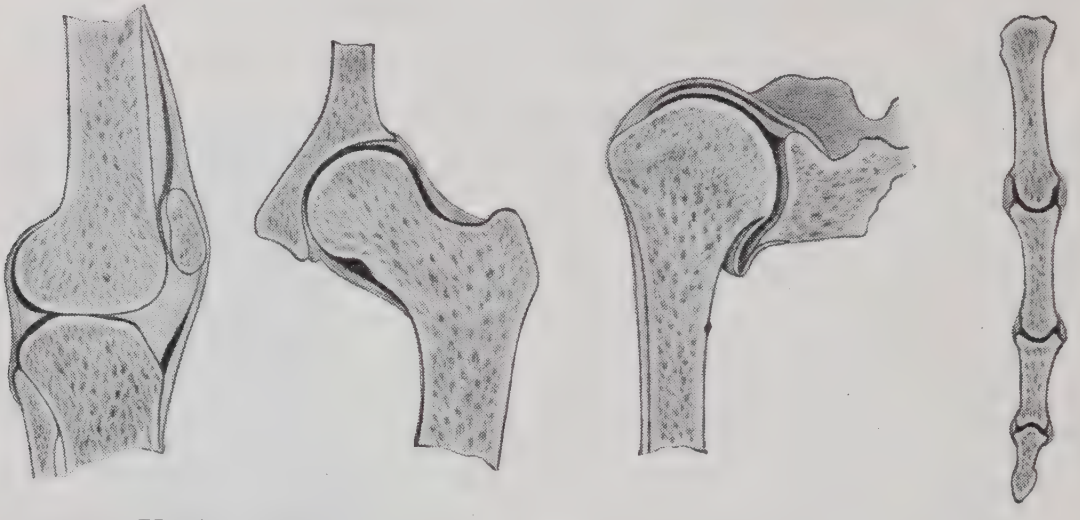


FIG. 273. Various kinds of joints. At the left is a hinge joint in the knee. Notice the *knee cap*, the small oval-shaped bone at the knee. Second from the left is a ball-and-socket joint in the hip. Next to it is a ball-and-socket joint in the shoulder. At the right are hinge joints in the fingers.

is, it can move back and forth only like a hinge. In your hips and neck are *ball-and-socket joints* that can move and twist in all directions. Some of the toughest materials in the body tie the bones together at the joints. These tough sheets and bands of material are the *ligaments*. When you think of how hard we use our joints, you can see that the ligaments must be very strong to keep the bones from being pulled apart or moved in the wrong directions.

Sometimes an unusual twist or an accident stretches the ligaments and makes the joint sore and "stiff." We say that the joint has been *sprained*. The soreness warns us not to use that joint freely until the cells have repaired the damage. A pull or a twist may even pull the bones apart until they slip out of their usual places; then we

say that we have a *dislocation*, or that the bone is "out of place." Of course, the remedy for a dislocated joint is to pull the bones apart again and let them go back into their usual places.

The ends of the bones that rub together are enlarged and covered with a layer of smoothest cartilage. Like the bearings of our machines, each joint is lubricated by an oily fluid. All around the joint, under most of the ligaments, is a kind of sack that keeps the lubricating liquid in the joint and keeps other substances out. If an injury tears this sack and allows the liquid to leak out, the joint may not work.

In a number of ways your joints are like some of the bearings in our best machines. They are lined with a material that wears very smooth. They are lubricated. They have coverings to keep the oil in and to keep other materials out. Millions of years before man invented good bearings for his machines, joints with these features were growing in the bodies of men and animals.

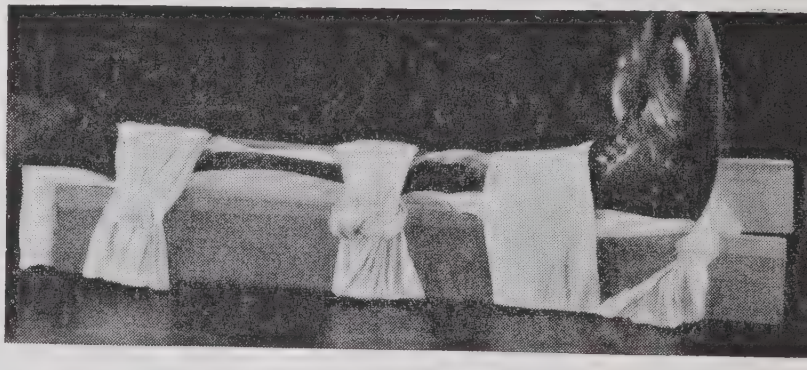


FIG. 274. When a bone is broken, the parts should be held rigid by the use of *splints*. Otherwise the broken ends of the bone may grind against each other and even tear the flesh, thus doing more damage.

Self-Testing Exercises

1. State three good points about the way our joints are constructed.
2. What is the main use of the ligaments around joints?
3. Name two important kinds of joints and tell how they are different.
4. What is a sprain? A dislocation?
5. Why should broken bones be held rigid by splints?

FIG. 275

HOW DO MUSCLES SUPPORT AND MOVE THE SKELETON? Have you ever watched a juggler perform? To keep even a single stick balanced on the end of a finger is hard for most of us. But a juggler can often keep several things in the air, one on top of the other. We wonder how he does it, but we give little thought to the juggling that each of us must do just to walk.

Try to imagine a human skeleton with more than 150 perfectly lubricated joints held together by flexible ligaments. Stand it up on the floor; it immediately collapses into a heap of bones. It will not even stand in a corner. About the only way to have a skeleton look like a skeleton is to hang it up. Yet you make your jointed skeleton stand and sit, walk and run. You do these complicated "juggling" stunts with your muscles, which are controlled by messages sent through your nerves.

In your body are three kinds of muscles. The kind we are interested in now are those attached to the bones and called the *skeletal muscles* (Figure 275). Another kind is found in the walls of the food tube and in other parts of the body. The third kind is found only in the heart. Each kind of muscle is made of a different kind of cell. The skeletal muscles are the only ones that we can make move. We cannot control the other muscles.

If possible, you should examine some real muscles while you are studying how they work.

Experiment 44. *What Is the Nature of Muscles?* (*a*) The lean meat of all common animals is composed of muscles. You can learn about muscles by looking carefully at the meat in butcher shops, the meat on chickens that are being dressed, and the meat you eat, and by feeling your own muscles through the skin. What color are muscles? What shape? If possible, get a piece of bone that has a tendon still attached to it. See if you can pull the tendon loose from the bone. Fine out, if you can, how the tendon is attached to the muscle and to the bone.

b) With needles or other sharp-pointed instruments, pick a small piece of lean beef to pieces to see how it is put together. Do the fibers run lengthwise or crosswise? What holds them together? How long are they? Put a few of the fibers in some water on a glass slide and examine them under the low power of a microscope.

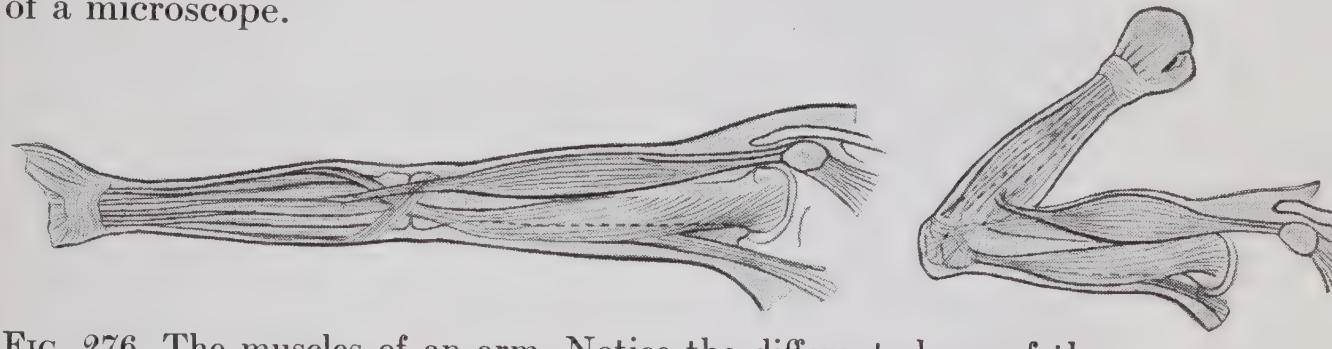


Fig. 276. The muscles of an arm. Notice the different shape of the muscles when the arm is bent at the elbow.

Skeletal muscle material has a characteristic reddish color. When you pick it to pieces, you find that it is made up of tiny fibers, held together by very fine threads called *connective tissue*. By feeling the calf of your leg or the large *biceps* muscle in the upper arm, you can learn the shape of most muscles. They have a thick central part that becomes smaller toward each end. At each end the connective tissue of most muscles extends out to form a strong white cord, or *tendon*, that is attached to a bone.

The tendon may be very short, or it may be quite long. The largest tendon in the body goes from the calf of the leg to the heel. Some long tendons connect our fingers with muscles in the forearm. If you hold your hand or wrist while you work your fingers, you can feel the movements of the tendons. With the muscles and tendons arranged in this way, your hands can be more slender and useful than if the muscles were in the fingers. The muscles can also be kept warmer and have a better blood supply.

The cells of muscles are made in some peculiar way that allows them to get shorter when they receive the right kind of message from nerves. Thus, a muscle in action gets shorter, or contracts, and pulls on its tendons and on the bones to which its tendons are attached. But the muscle cannot push the bone back again after it has shortened and drawn it up. Thus, there must always be a second muscle or set of muscles attached to the opposite side of the bone to pull it back again. For this reason we say that muscles almost always work in pairs.

There are about fifty-four muscles in each leg. When you take a single step, the fifty-four muscles in one leg, and many others in the body and arms, are juggling the bones of that leg and of the body, while the fifty-four muscles of the other leg move it forward and get ready to take their turn at juggling. To do this time after time with reasonable accuracy, each muscle must be nicely controlled by messages that come to it through the nerves.

Self-Testing Exercises

1. Write a paragraph describing a single large muscle.
2. What is the use of tendons in your body? Locate a tendon in your body and explain what tendons are like.
3. Explain why the work of the muscles in our bodies is really worthy of admiration.

WHAT AND WHERE ARE THE PRINCIPAL SYSTEMS OF THE BODY? We have been thinking about two of the sets, or *systems*, of organs found in our bodies. These two systems are the *skeletal system* and the *muscular system*. Together these two systems make up more than half the weight of your body. Yet without several other systems of organs in the body the bones and muscles would soon die.

As you probably know already, the main part, or *trunk*, of the body contains a large space filled with organs (Figure 277). A partition divides this space into two "rooms." The partition is made of muscle and ligament and is called the *diaphragm*. It passes across the body at the lower end of the breast bone and curves downward along the edges. Above the diaphragm is the upper "room," the cavity of the chest, or *thorax*. Below the diaphragm is the cavity of the belly, or *abdomen*.

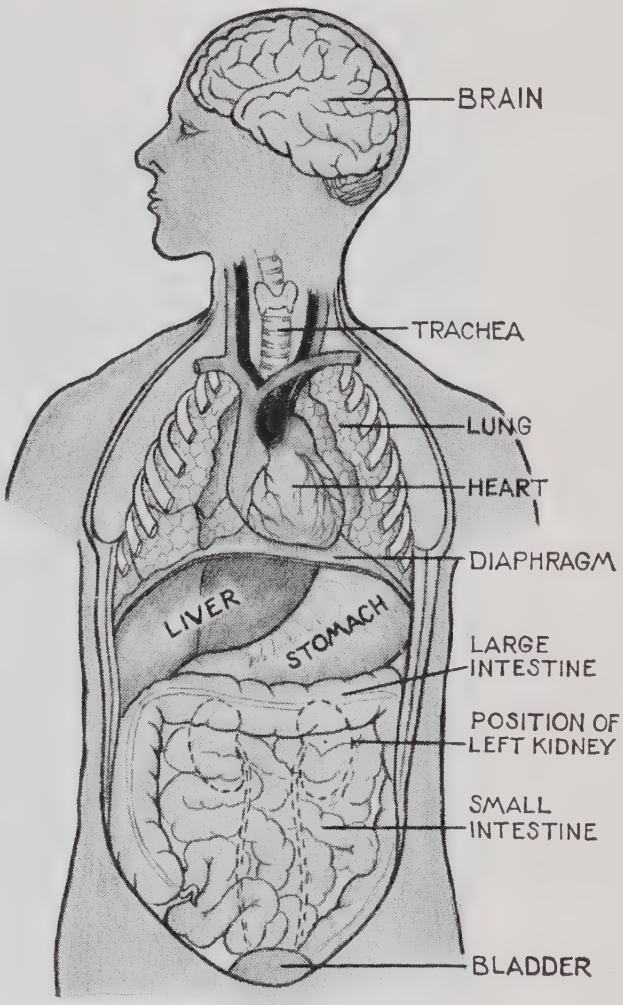


FIG. 277. Organs in the trunk of the human body

The lungs, which are the most important parts of the breathing system, or *respiratory system*, fill the larger part of the chest cavity. The main organs of the food system, or *digestive system*, are the stomach, intestines, liver, and pancreas. These are in the lower, or abdominal, cavity of the trunk. Behind the liver and stomach, at the sides

of the backbone, are the two kidneys. These are the main organs of the *urinary system*, that takes certain kinds of wastes out of the blood. In the lower part of the abdomen or closely connected with it are the organs that make new human bodies, *the reproductive system*.

The blood system, or *circulatory system*, as you know, goes all through the body, but its central organ, the heart, lies in the thorax just back of the lower third of the breastbone. The controlling system, or *nervous system*, also runs through the whole body, but its central parts, the *brain* and *spinal cord*, lie in cavities of bone, where they are well protected. The brain is in the skull, and the spinal cord is in the backbone.

In the problems that follow this one, you will learn how the blood system, the food organs, the breathing organs, and the urinary system do their work, and how they keep the whole body going. Later in your study of science you will learn about the others.

Self-Testing Exercises

1. Make a list of the sets of organs in your body. After the name of each one, tell briefly what its work is.
2. Name and give the location of the two main cavities in your body. Name some of the organs located in each one.

Problems to Solve

1. How many hinge joints can you find in your body? How many ball-and-socket joints? Write out lists.
2. List as many ways as you can in which a joint in your body is like a good bearing in a machine. List also as many differences as you can.
3. Give reasons for believing that your blood system extends all through your body.
4. Give reasons for believing that your nerve system reaches into practically all parts of your body.

Problem 2:

HOW DO OUR CELLS KEEP ALIVE?

HOW DO CELLS GET ENERGY TO DO THEIR WORK? Earlier in your study of science you learned that all living things are made of tiny living pieces called *cells*. These tiny cells in your body really do everything that you do. Your body is alive only when its billions of cells are alive and working as they should be. These cells must have the same things to keep alive that any animal must have —food and oxygen. But can you explain what a cell does with the food and oxygen that it must continually have?

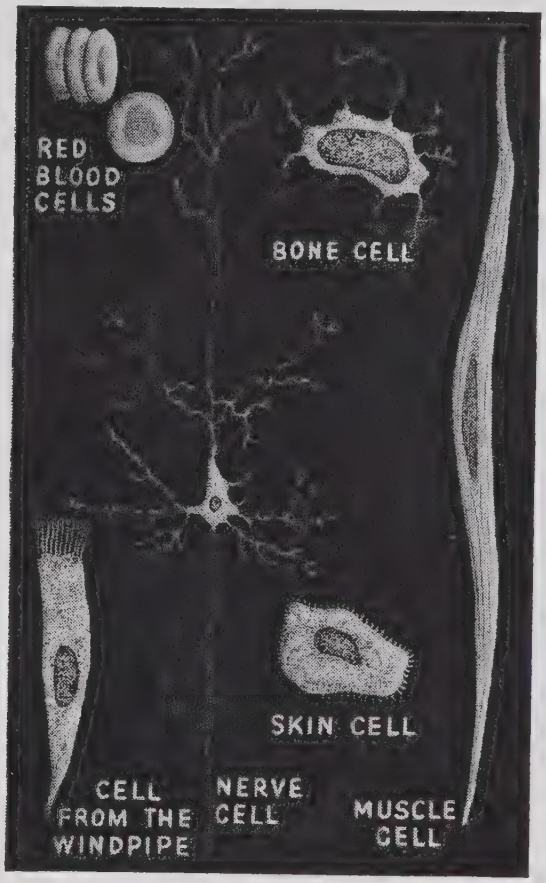


FIG. 278. There are many kinds and shapes of cells in the body, but they all have in them living protoplasm and a nucleus.

Since living cells are active, you know they must have energy or they could not be "doing things." We can often notice the heat energy and the energy of motion that is used by the cells. Can you tell how a cell gets its energy? Our stoves get heat energy to warm our rooms by burning fuel. Locomotives get energy to pull trains by burning coal or oil. You have learned that burning is a chemical change of fuel and oxygen into other substances. The oxygen unites with the fuel and changes it into oxides of the elements that are in the fuel. When this change takes

place, the chemical energy of the fuel changes into heat energy that can be used, as you learned in Unit 5.

Cells get their energy in almost the same way a stove does. They cause the oxygen they receive to unite with food; that is, they *oxidize* the food. Oxidation changes the chemical energy of the food into the kinds of energy that the cell, and therefore the body, can use. Much of the useful energy is heat and motion, or kinetic energy. The cell must then get rid of the used materials and take in more food and oxygen to keep the process going.

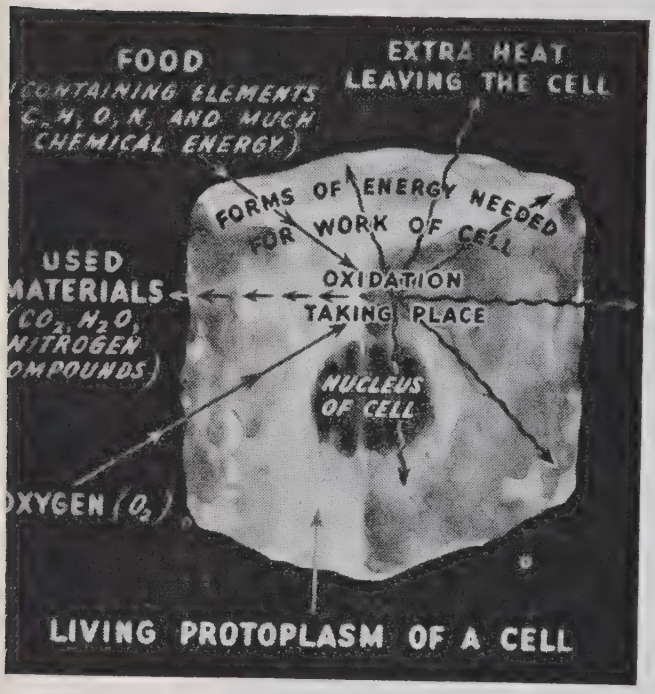

FOOD
(CONTAINING ELEMENTS C, H, O, N, AND MUCH CHEMICAL ENERGY)
EXTRA HEAT LEAVING THE CELL
FORMS OF ENERGY NEEDED FOR WORK OF CELL
USED MATERIALS
(CO_2, H_2O, NITROGEN COMPOUNDS)
OXIDATION TAKING PLACE
NUCLEUS OF CELL
OXYGEN (O_2)
LIVING PROTOPLASM OF A CELL

FIG. 279. Be sure that you can explain this diagram.

A diagram will help you understand how a cell gets its energy (Figure 279). In the diagram you see food and oxygen going into the cell and uniting. Useful forms of energy are made from the hidden energy that was stored in the food. If the cell is a muscle cell, the chemical change of the food makes it move. Probably all cells give out heat energy that keeps the body warm. The oxidized food is of no further use; so the cell gives it out.

Notice from the diagram that our food contains the element carbon (C). Can you tell where and in what form the used carbon leaves the body? You can find out by doing a simple experiment.

EXPERIMENT 45. *Where and in What Form Does Used Carbon Leave the Body?* Fill a beaker or glass one-third full of clear limewater. Bubble your breath through the limewater with a soda straw or a small glass tube (Figure 280). What happens to the limewater? Only the used or waste form of carbon, called

carbon dioxide (CO_2), can cause this change in limewater. Can you now answer the problem of the experiment?

The oxidized form of carbon is the gas, carbon dioxide. We breathe out large amounts of carbon dioxide. You have probably known this for some time, but you may not have connected it with the use of food in your body. Oxidized hydrogen is water (H_2O). Much water is needed in the body; so the water formed by the oxidation of food is just added to all the other moisture in the body. Later you will learn how the nitrogen wastes leave the body through the kidneys.

FIG. 280

In thinking about the oxidation in our cells, you must be careful not to get wrong ideas. Sometimes boys and girls get the idea that there is a little fire in each cell. That idea is not true, because the oxidation of the food goes on without high temperature and flame. Except in the muscle cells, the chemical change in the food goes on slowly, somewhat like the rusting of iron.

Another wrong idea that many people have is that their food is oxidized in the lungs, the heart, or the stomach. If you are thinking, you can see how that idea is wrong. Of course the cells in those organs are oxidizing their share of the food. But every living cell in the body needs energy. Each living cell in your fingers, toes, brain, and muscles uses oxygen to oxidize food. Thus each cell in your body must receive food and oxygen and get rid of used materials if it is to keep alive.

Self-Testing Exercises

1. Explain how cells get the energy they need.
2. Where and how is carbon dioxide formed in our bodies?
3. What did Experiment 45 show?

How do materials get into and out of cells? You have learned that each living cell must always be oxidizing food. When energy has been gotten out of the food, the used materials must leave the cell. How does this constant stream of food and oxygen go into each cell in the body, and how do the used materials pass out of the cells? You can learn one way these substances travel by doing a simple experiment.

Experiment 46. *How Does One Material Move through Another?* Fill a test-tube with agar jelly. To prepare this jelly, put about four grams of agar-agar and 100 cubic centimeters of water in a beaker. Slowly heat the mixture and stir it until the agar-agar has apparently dissolved. Stand the test-tube in a vertical position and pour in the agar-water mixture until the tube is a little more than level full. (As the tube cools, contraction of the jelly will leave it no more than level full.)

When the jelly has hardened, turn the tube upside down in a glass that contains about an inch of fountain-pen ink. After an hour or less lift the tube out, wipe the liquid from the outside of the tube, and examine the jelly to see how far the ink has gone into the jelly. Be careful not to shake the jelly loose from the sides of the tubes.

Replace the tube just as it was. Notice and measure the rise of color into the jelly once each day until it reaches the end of the tube. Can you explain how the colored material rises in the tube that is already full of the agar jelly? Does the color move through the last inch of the tube as rapidly as it does through the first inch?

This experiment is very important in learning how our cells are fed. The colored material in the ink is dissolved in water; that is, each molecule of colored material is separate from the other molecules. Thus the molecules are able to bounce around rapidly and move through very small spaces.

If your experiment was correctly done, you saw how the molecules of colored material gradually moved up through the jelly until they reached the top of the tube. This spreading of a material from one place to another by the movement of the separate molecules is called *diffusion*. We say that the ink *diffuses* into the jelly. Only materials that are dissolved can diffuse. This experiment shows how dissolved food and oxygen get into and out of the cells. They diffuse into the jellylike protoplasm of the cells, and the used materials diffuse out, much as you saw the ink diffusing into the jelly.

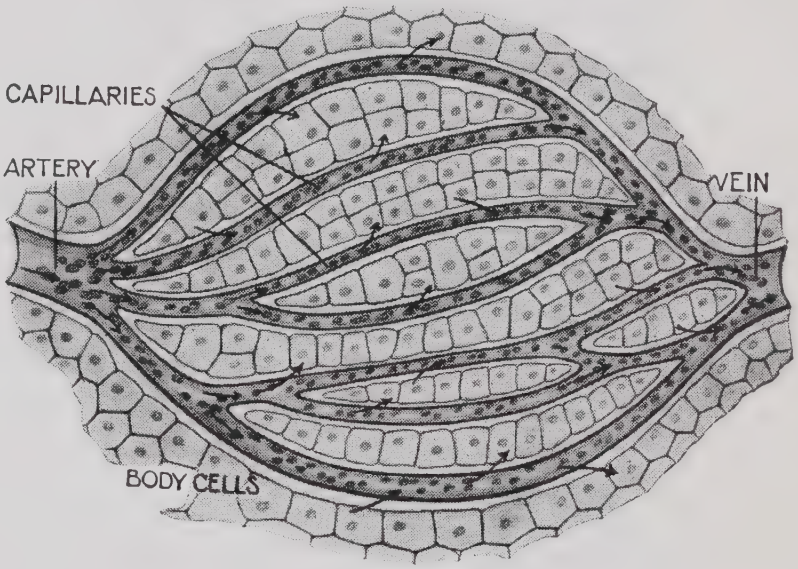


FIG. 281. How blood flows near the cells

Diffusion, as you have seen, is a very slow process. To keep a constant supply of food coming in, and to get rid of waste materials as they are made, the body must be constructed so that diffusion takes place only through a very small distance. This is made possible by the tiny blood tubes, or *capillaries*, that extend through all parts of the body. There is hardly any place in the body thicker than a hair that does not have one of these tiny tubes.

Figure 281 shows how blood in the capillaries brings material near the cells and carries away the waste materials that diffuse into it. The cells in this diagram stand for any cells in the body. They may be muscle cells, brain cells, stomach cells, or any other kind of cell. In the drawing they are of course magnified thousands of times.

The walls of the capillaries are only one cell thick. The blood running through these capillaries has a plentiful supply of the materials the cells need. Thus the materials that are used up by the cells will diffuse from the blood into the cells. At the same time the cell will have an extra supply of used materials, and these will diffuse out into the blood.

WHAT MUST THE BODY DO TO KEEP ITS CELLS ALIVE? A single cell of the body is so small that it cannot be seen without a microscope. Such a tiny cell is "lost" among the billions of other cells in your body. To take care of each cell and help it keep alive and working, the body organizes its cells into groups.

One group of many kinds of cells is called the food system or digestive system. It has the special duty of supplying the blood with food to take to all the other cells. Another set, called the respiratory system, has the work of letting oxygen get into the blood to go to all the other cells. The kidney system has to get the nitrogen wastes and other materials out of the blood. The cells of the circulatory system have the duty of sending blood with food and oxygen into every part of the body and of bringing it back again with whatever the cells have given out.

Thus, you see, to keep all the cells alive each different set of cells in the body does some special thing for all the others. This is called the "division of work" or the "division of labor" among the cells. You know that some animals, such as bees and ants, divide the work among themselves. Men also divide their work, some raising the food, some preparing it for use, some making clothes, and so on. In the same way our cells divide the work that is to be done by the body, and each kind of work is done by a special kind of cell.

Self-Testing Exercises

1. How do food and oxygen move into the cells of our bodies?
2. In what condition must a substance be so that it can diffuse into a cell?
3. What are capillaries? Where are they found?
4. Why is it very important to have blood flowing through the capillaries?
5. Explain why we say that there is a division of work among the cells of the body?

Problems to Solve

1. Make a list of the ways the body is like a locomotive. Then make a similar list of the ways in which the two are different.
2. Tell the story of some food material from the blood that is used by a cell until it is back in the blood again.
3. Explain why most living things die when they are unable to get oxygen.
4. Give some examples of diffusion outside the bodies of living things.
5. Why do the smallest animals not need a blood system?
6. How are the cells of your body like the people of a great city? How are they different?

Problem 3:

HOW DOES THE BLOOD MOVE THROUGH THE BODY?

EVER SINCE man began to think, he has connected blood and the beating of the heart with life. If the blood is lost or the heart stops beating, a man or an animal dies. Do you see now why these facts are true? It is because blood carries food and oxygen to the cells and used materials away from them. And the heart must beat to keep the blood flowing. To know only these things about one's blood system does not satisfy an educated person. He wants to know how the heart pumps the blood, how

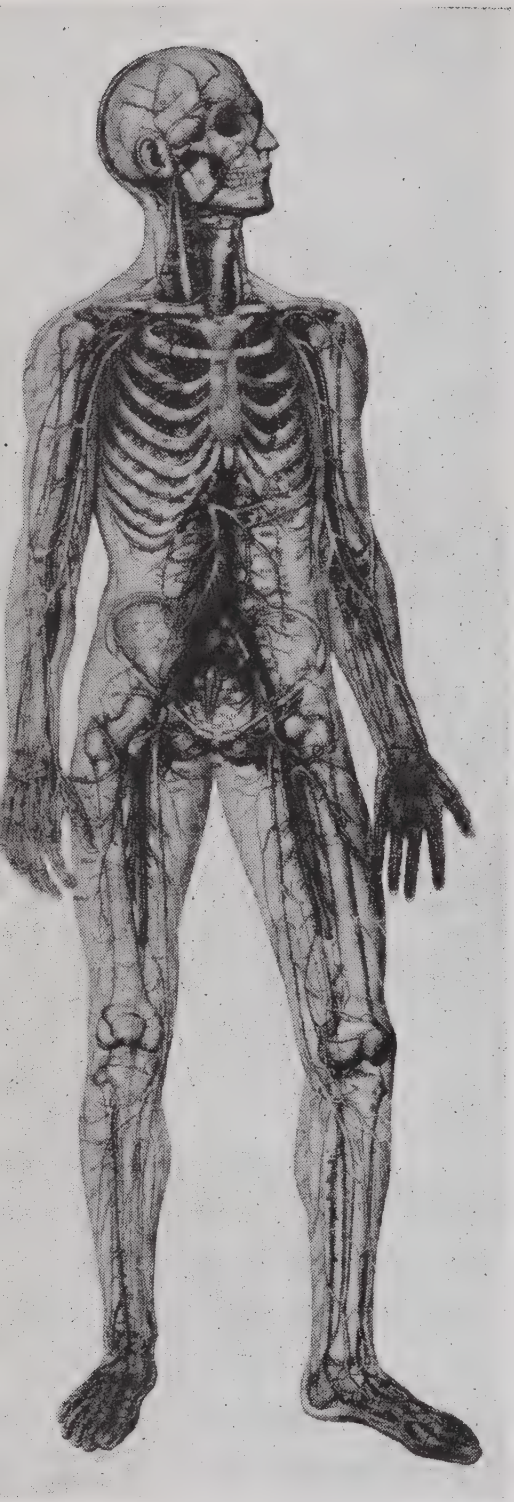


FIG. 282. A general picture of the blood tubes in the human body

the blood travels to every part of the body, and how it gets back to the heart.

The blood system is called a circulatory system because the blood travels in a kind of circuit or "circle" through the body. Thus it is used over and over again. All the blood that goes out to one part of the body, such as an arm, comes back and goes out again to that part or to some other part. There are five different kinds of parts in the circulatory system that you should know about. The first part of the circulatory system is the blood itself, which carries the different materials as it travels about the body. The second you already know; it is the heart, which pumps the blood and thus makes it flow.

The third part of the circulatory system consists of *arteries*. Arteries are blood tubes, or blood vessels, that carry the blood from the heart out to other parts. Only two large arteries leave the heart, but they branch again and again until the tiniest arteries reach every part of the body. Fourth are the capillaries that you found near the cells in all parts of the body. The blood flows from the arteries into capillaries. Finally, we must have some tubes to lead the blood back to the heart. These tubes are the *veins*. You can see some of them in the skin on the surface of the body.

WHAT IS BLOOD? First let us learn some of the more important facts about the blood. If you have a compound microscope, you can see for yourself what the main parts of the blood are.

EXPERIMENT 47. *What Is the Appearance of Blood under a Microscope?* Have a very clean glass slide and cover-glass ready. Dip a clean new needle in strong alcohol and rub a bit of the alcohol on the side of your thumb near the nail. The alcohol will kill any germs that are present. Prick the skin where you soaked it with alcohol and get a drop of blood to put on the slide. Or you may have another person get a drop in the same way from the lobe of your ear. Put a very small drop of the blood on the slide and spread it out very thin by putting the cover-glass on it.

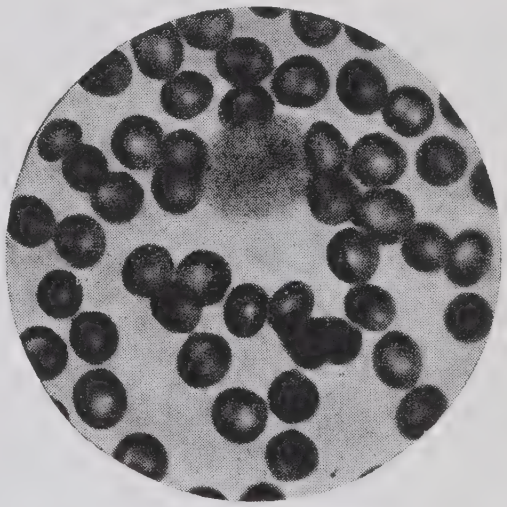


FIG. 283. Under the microscope the red blood corpuscles look like this. In the upper center is a white corpuscle.

Leave the cover-glass in place and look at the blood under the high power of the microscope. Look for a multitude of tiny yellowish disks. These are the *red corpuscles*, or red-blood cells. What is their real shape? Can you see that they are floating in a colorless liquid? If you can find a place where the blood is extremely thin on the slide, you may be able to see some irregular white blood cells, or *white corpuscles*.

If you were successful in doing Experiment 47, you saw very, very many yellowish disks, called *red corpuscles*, floating in the blood. Each one of these is a single cell. When we see a great many of these together, they appear red. They are colored by a chemical compound, called *hemoglobin*. A single drop of blood contains about twenty

million of these cells. There are enough in the blood of a grown person to cover a surface equal to one half an acre. The main duty of the red-blood cells is to carry oxygen. The hemoglobin in the cells combines easily with oxygen and gives the oxygen out again when the blood gets near the cells.

By looking a little more closely at a thin layer of blood under a microscope, we can find in it a smaller number of irregular, transparent cells. Some of these *white corpuscles* help protect the body from disease germs. The red and white cells make up about one-third of the blood. The remainder of the blood is mostly water in which are dissolved or suspended many different substances, such as salt, food, minerals for the formation of bones, and chemicals that regulate the work of the body.

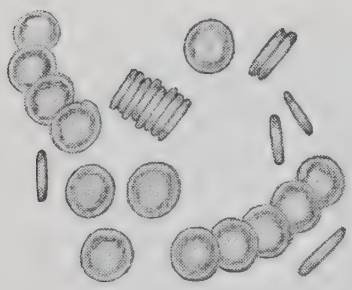


FIG. 284. Under the microscope the corpuscles look spherical. They are really disc-shaped, like these.

HOW DOES THE BLOOD TRAVEL THROUGH THE BODY? Let us first get an idea of the heart and how it works. If you will look at Figure 285, you will see that the heart is separated into two main parts by a partition. Blood from one side of the heart cannot enter the other side of the heart. We usually think of the heart as a pump, but actually it is two pumps. What happens during a single stroke of these pumps, that is, during one heart beat? The walls of the heart are made of thick, heavy muscles. When they contract, they squeeze blood out of the heart; when they relax, blood comes into the heart.

Let us suppose that the muscles are relaxed. Blood will enter the right side of the heart through veins that bring blood from all parts of the body. Blood will enter the left

side of the heart through veins that bring blood from the lungs. Now the muscles contract. What happens? The blood in the right side of the heart is forced into an artery that carries the blood to the lungs. The blood in the left side of the heart is forced out into an artery called the *aorta* that carries blood all over the body. Notice that there is a *valve* between each receiving chamber and the pumping chamber below it. When the pumping chambers contract, these valves close so that the blood will not be forced backward into the receiving chamber. Notice also the valve into the aorta and the valve into the big artery.

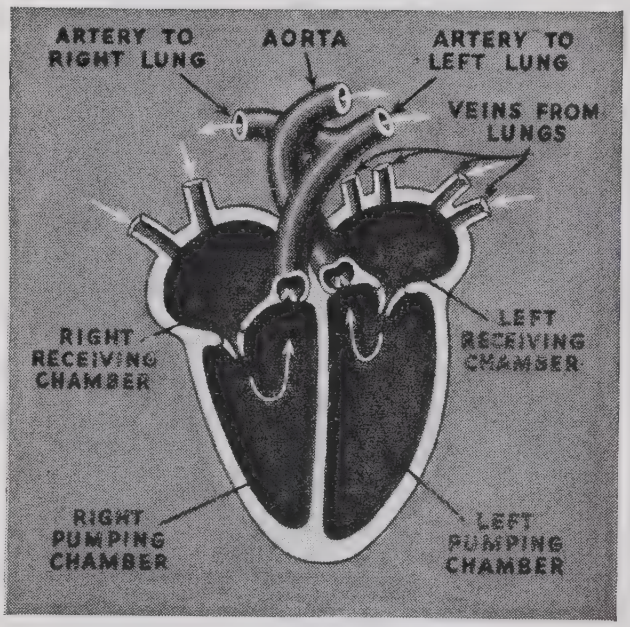


FIG. 285. Diagram of the human heart

Now that you have in mind what the heart does, let us get a kind of "bird's-eye view" of the way in which the blood travels about the body. Figure 286 will serve as a kind of map for you. It is just a rough diagram of the real blood system, as you can see by comparing it with Figure 282, page 372.

The first thing to remember about the way the blood travels through the blood vessels is this: Almost everywhere in the body the blood passes from the heart into an artery, from an artery into capillaries, from the capillaries into veins, and from veins back into the heart again. The second important idea about the circulation of the blood through the body is connected with the double heart.

If you will start at any point in Figure 286 and follow

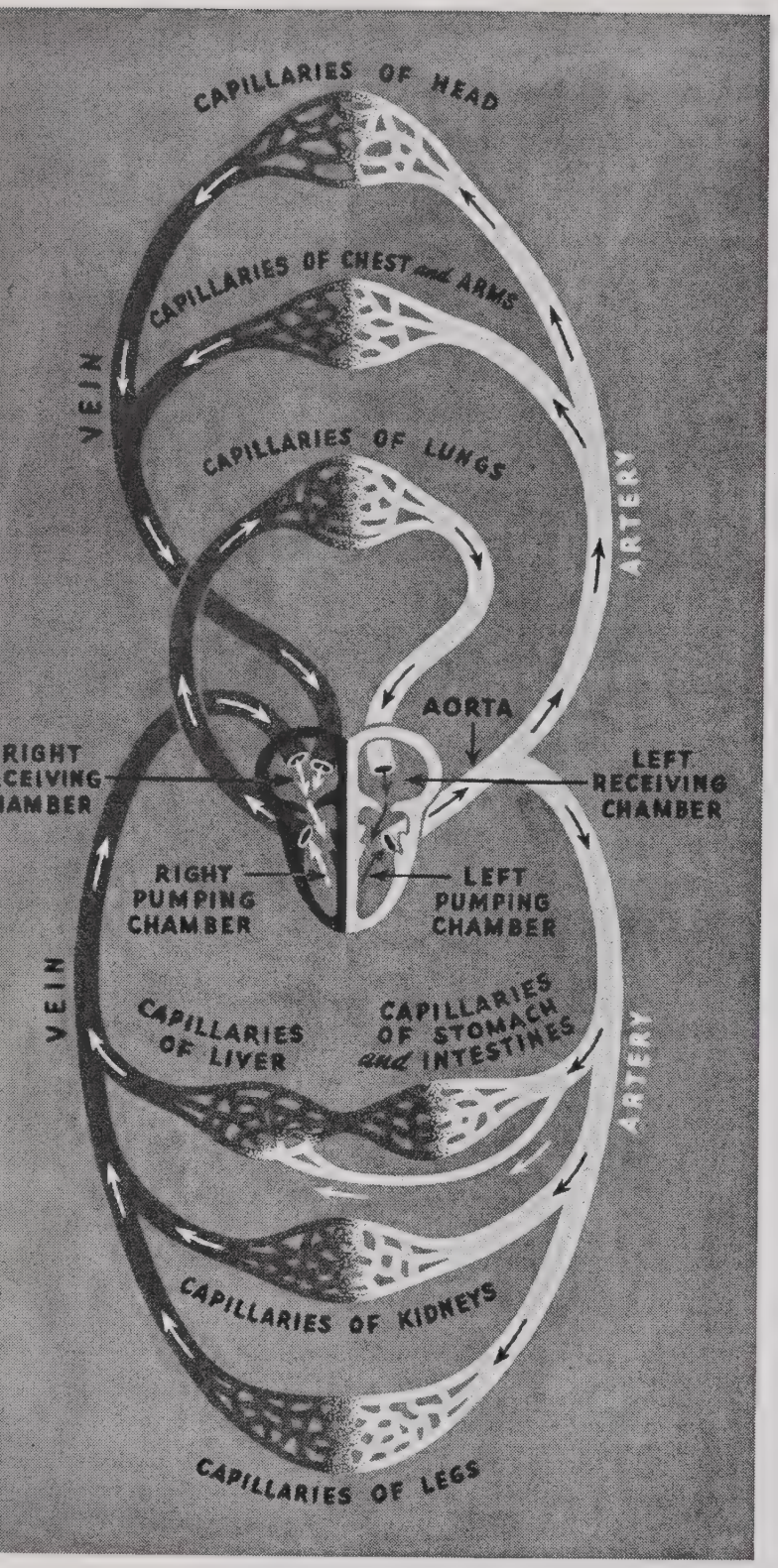


FIG. 286. Diagram of the circulatory system of the human body

the arrows as the blood would go, you will discover this important fact about the circulation: Every time the blood comes back to the heart from a lung, it goes into one side of the heart, the left side. But every time the blood comes to the heart from any other organ, it goes into the other side, the right side.

Now you can see the reason for a partition in the heart. One side pumps only blood that contains oxygen and sends it to all parts of the body except the lungs; the other side pumps only blood that contains carbon dioxide and sends it to the lungs. This is called a double circulation. Every drop of blood in the body goes through the lungs every time it makes a round trip through the body. This plan makes sure that all of the body will receive plenty of oxygen if the lungs are working right.

The third thing to remember is the general plan by which the important organs of the body are supplied with blood. Blood must be sent to the muscles, brain, bones, and skin to provide them with oxygen, food, and building materials. Blood must go to the small intestine to get digested food. Blood must go to the kidneys to have the nitrogen wastes taken out. To supply all these organs, the heart pumps all the blood from the lungs into the large aorta. Just as this artery leaves the heart, small branches turn back into the heart muscle itself to supply the heart cells with food and oxygen.

A short distance from the heart large branches are sent up to the head and arms. In Figure 282, page 372, you can plainly see these big arteries in the arms. The main artery then turns downward. A large branch goes to the digestive organs, and then two other large branches enter the kidneys. All along the artery are many smaller branches that carry blood to various parts. At the lower end of the abdomen the large artery divides into two smaller ones. One goes into each leg, as you can see in Figure 282. In this way every part of the body receives its share of the blood that contains oxygen.

The heart and arteries are parts of the body that frequently give trouble when the body begins to wear out. A good healthy diet with little or no alcoholic drink, plenty of rest, reasonable exercise, and well-controlled emotions seem to be the most important ways of helping the circulatory system last longer. The heart is one of the parts often injured by germs and the poisons from disease germs, about which you will learn in Unit 9. Thus it is important to avoid these diseases wherever possible, and to follow the directions of a good doctor when you have a disease. Especially when you are past middle life, that is, after

about forty years of age, you should have the advice of a physician, not only in times of illness, but also on how to care for your everyday health.

Self-Testing Exercises

1. Name the important parts of the circulatory system and tell what each one does.

2. What three important parts of the blood can be noticed under a microscope? Tell one thing that each part does.

3. Explain how the heart pumps blood?

4. Why is the circulation of blood in the body called a double circulation?

FIG. 287. It is well to know how to use a *tourniquet* to stop bleeding from a wound.

Problems to Solve

1. Under what circumstances would you expect the heart to pump more blood than usual? Find by feeling your pulse how many times your heart usually beats per minute. Then, when you think your heart is probably working harder than usual, count its beats again. What do you learn?

2. In how many places in your body can you feel a "pulse"? Make a list of the places. Under each of the places is an artery.

3. Find in some physiology or first-aid book how to stop dangerous bleeding from a cut. Look for diagrams that show the location of blood vessels that may be closed by pressure to stop bleeding.

4. The walls of one ventricle of the heart are much thicker and heavier than the walls of the other ventricle. Do you think the thick-walled side pumps blood to the lungs or to other parts of the body? Give your reasons.

5. Compare the blood system of your body with the railroad system of a country. In what ways are they alike? In what ways are they different?

6. In which part of the circulatory system do you think the blood has the highest pressure? Why? In which part do you think the pressure is lowest? Why?

Problem 4:

HOW DOES OUR FOOD DISSOLVE AND GET INTO THE BLOOD?

WHAT IS THE STRUCTURE OF THE DIGESTIVE SYSTEM? You have learned that materials cannot diffuse into and out of the cells of the body unless they are dissolved. However, if you will take some meat or bread and stir it with water, you will find that the meat or bread does not dissolve. Some foods like sugar dissolve, but most foods must be changed chemically into soluble materials before they can get into the blood and be carried to the cells. To understand how the digestive system dissolves food, you will need first to know how the digestive system is put together.

A map of any system of the body is very helpful in understanding its work, just as a road map is helpful in finding your way about in a car. However, you must remember that a map does not show all the details. Figure 288 is a map of the digestive system. Notice that the main part of the digestive system is a tube that goes from the mouth to the *anus* at the lower end of the body. The food tube is much longer than the body. In an adult person it is about thirty feet long. So part of it is coiled inside the abdomen.

The food tube is often called the *alimentary canal.* It is lined with a special layer of cells called the *mucous membrane.* The cells of the mucous membrane give out, or *secrete,* a slimy material, called *mucus.* This material

lubricates the membrane so that food materials can pass through the tube easily. You can feel the slick mucus on the inside of your mouth.

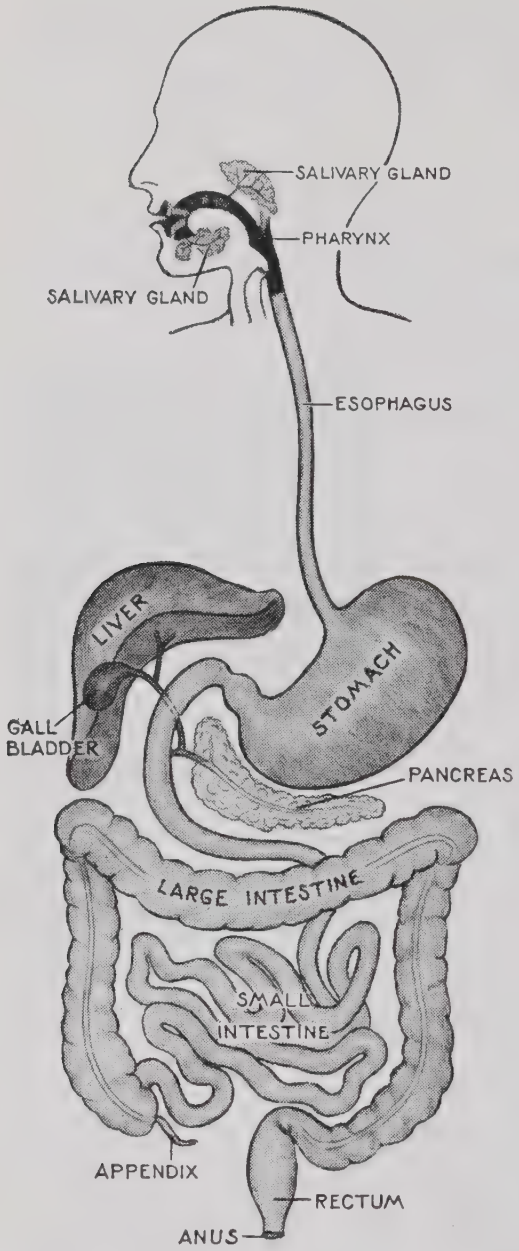


FIG. 288. The digestive system

The part of the food tube just below the mouth is called the *pharynx*. Then comes the *esophagus*. This is a rather narrow tube, but it is able to stretch a great deal. Just below the diaphragm the tube widens to form the *stomach*. After the stomach comes the long, *small intestine*. The lower end of the small intestine opens into the side of the *large intestine*.

Notice that some parts of the digestive system are not parts of the food tube. These parts are the *glands* that make chemicals to pour on the food and help dissolve it. Opening into your mouth through tiny tubes are several *salivary glands*. These glands make the watery material, or *saliva*, that keeps your mouth moist. The linings of the stomach and of the small intestines contain many very small glands that make chemicals to help dissolve your food.

Both the *pancreas* and the *liver* are connected to the small intestine by small tubes through which their chemi-

cals are poured on the food as it passes through. The tube coming from the liver is also connected to a kind of sac, the *gall bladder*. The liver fluid, or *bile*, is stored in the gall bladder when it is not needed for the digestion of food. In addition to making chemicals to help with digestion, both the liver and the pancreas have other important duties. You can find out about these other duties by looking in a physiology book.

Self-Testing Exercises

1. Close your book and draw a "map" of the food tube. Show where the liver and pancreas pour their chemicals into the tube.
2. Make a list of the glands that pour digestive chemicals into the food tube.

HOW IS FOOD DISSOLVED? In Unit 10 of Book 1 you learned that there are three important classes of food materials: *carbohydrates*, such as starch and sugar; *proteins*, such as lean meat and white of eggs; and *fats*, such as butter and lard. Each different kind of food needs a different chemical to dissolve it. Thus several different chemicals are used in the food tube, and each different organ of the digestive system has a special work to do in preparing the food for the blood.

In the mouth the teeth cut and grind the food into small bits, so that the chemicals can dissolve it more quickly. While the food is being chewed, the salivary glands pour saliva on it. The chief value of saliva is to moisten the food and to lubricate it, so that we can swallow it easily. However, saliva contains a substance that helps in the chemical digestion of food. You can watch this chemical digest one kind of food in a test-tube.

EXPERIMENT 48. *How Does Saliva Help Dissolve Food?* (*a*) Put a lump of laundry starch about the size of a large pea or an equal amount of corn-starch into a beaker or pan. Add about

one-third of a glass of cool water. Mix the starch thoroughly with the water and boil it. Then cool the mixture by adding an equal amount of cool water to it. Notice the appearance of the starch mixture. Has the starch dissolved? Pour a little of the mixture into a test-tube and add one or two drops of weak iodine solution. What color do you get?

b) Put a piece of water-soaked cloth or a thin layer of soaked absorbent cotton in the bottom of a glass funnel or clean metal

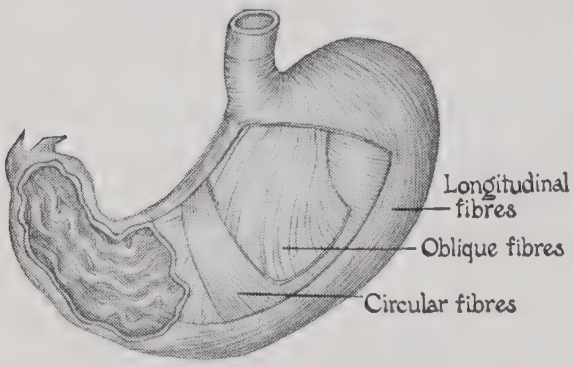


FIG. 289A. Muscles of the stomach. You can see that the stomach walls are made up of sheets of muscle running in different directions. These muscles expand and contract to churn the food in the stomach.

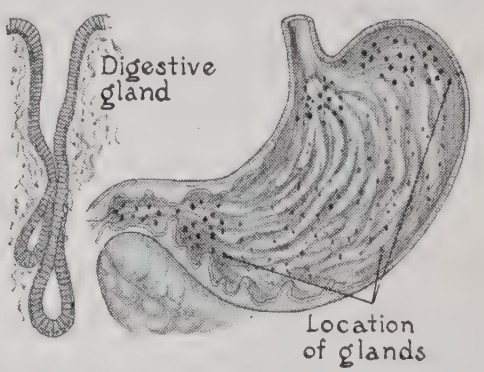


FIG. 289B. The black dots show about how the gastric glands are located in the stomach. At the left is a gland as it looks when it is magnified thousands of times.

funnel and stand it in a test-tube. Collect saliva in the funnel until the test-tube is at least one-fourth full of clear liquid. Test a little of the saliva with iodine as you did the starch mixture. Does it change color?

c) Fill the tube that contains the saliva with starch mixture and mix the two liquids thoroughly. After two or three minutes compare the appearance of the liquid in this tube with a sample of the starch mixture poured into another tube. Does the starch seem to have dissolved?

Test some of the starch-saliva mixture with iodine in a separate test-tube. It should no longer show the color due to starch. What has become of the starch? If the starch has not entirely disappeared, let the mixture stand longer and test again. (The results of this experiment will be better if the starch

mixture and the saliva can be kept at the temperature of the body by standing the test-tubes in warm water.)

Experiment 48 shows that saliva contains some substance that changes starch into another material. Chemical tests show that the new material is one kind of sugar. Sugar is soluble and can be absorbed into the blood, while the body cannot use starch. Thorough chewing helps digestion by grinding the food into tiny bits and by giving time for the chemical in the saliva to change the starch to sugar, or *digest* it.

When we swallow, a layer of muscles around the esophagus pushes the food or drink from the throat into the stomach. The stomach is important as a place to store a meal, but much digestion also takes place in the stomach. Tiny glands in the lining of the stomach (Figure 289B) pour a mixture of chemicals, called *gastric juice*, on the food. One of these chemicals is the sour hydrochloric acid. Another, called *pepsin*, changes proteins, so that they can dissolve. (See Book 1, page 344.) Strong layers of muscle fibers in the wall of the stomach (Figure 289A) stir the food and mix it with the gastric juice. After the food is made into a pasty, half-liquid material, it is pushed little by little into the small intestine.

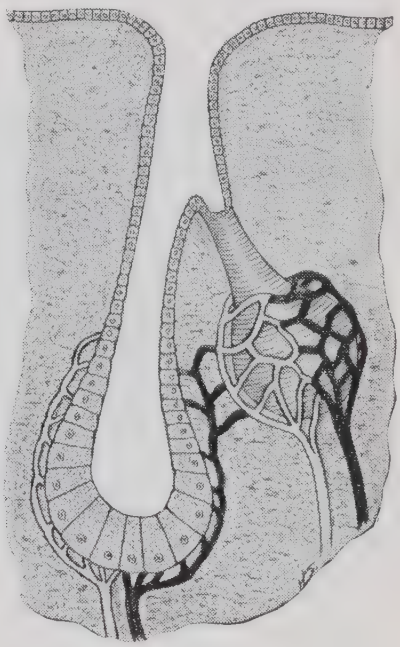


FIG. 290. At the left is a simple gland as it would look if sliced in half. Notice the cells that line the cavity. At the right is a gland as it looks uncut. The black lines are capillaries carrying blood to the glands.

As the stomach pushes the partly digested food into the upper end of the small intestine, bile from the liver

and *pancreatic juice* from the pancreas are poured into the intestine to mix with the food. The tiny glands in the lining of the intestine also pour a digestive juice on the food. The pancreatic juice contains chemicals that help to dissolve all three classes of food—fats, carbohydrates, and proteins; while bile helps digest the fats, and the intestinal juice helps digest the carbohydrates and proteins.

On the average, food requires about four hours to pass from one end of the small intestine to the other. In this organ the digestion of the food is completed, and the dissolved food is soaked into the blood, or absorbed.

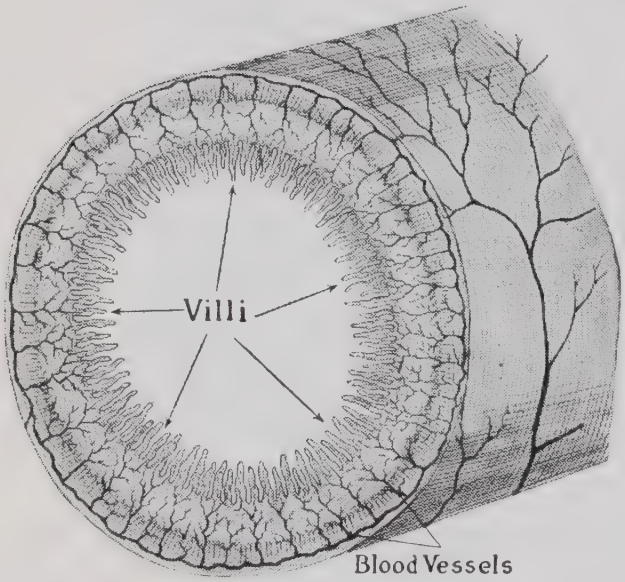


FIG. 291. Villi of the small intestines

Self-Testing Exercises

1. When saliva is mixed with cooked starch in water, the starch gradually disappears. What becomes of it?

2. State two ways in which the muscles of the food tube help dissolve your food.

3. How do chemicals from the glands along the food tube help dissolve food?

HOW DOES THE DISSOLVED FOOD GET INTO THE BLOOD? The dissolved food soaks into the capillaries in the lining of the small intestine almost as fast as it is digested. In order to take in the food so rapidly, the intestine must be well fitted for this work. The intestine is fitted for absorbing the food in several ways: (1) It has a very thin lining. (2) It contains a great many capillaries. (3) A great deal of its lining can touch the food; that is, the lining has a large area.

The intestine has a large area for two reasons. In the first place, the small intestine of a grown person is about twenty feet long. Besides this, it has thousands of tiny "fingers" about one twenty-fifth of an inch long that stick out into the liquid in the intestine and help to soak in the food (Figure 291). These tiny fingers are called *villi* (singular *villus*). In some parts of the intestine these villi make the absorbing surface fifteen times as much as it would be if the inside of the tube were perfectly smooth. This means that, with the help of the villi, those parts of the intestine can take in digested food fifteen times as fast as they could if there were no villi.

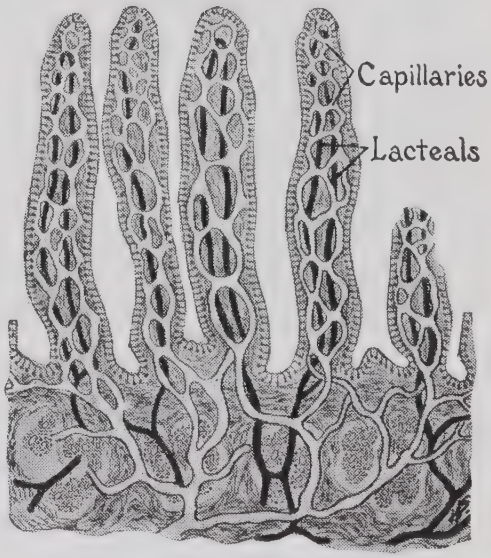


FIG. 292. A section view of villi

The dissolved carbohydrates go into the blood flowing through the capillaries in the villi. Digested fats go into small tubes called *lacteals* and then into a long tube that finally empties into a vein near the left shoulder. Scientists do not yet know why one kind of food goes into the lacteals while the other kinds go into the capillaries. Either way, however, the food finally gets into the blood to be carried near the cells that need it.

By the time the food has reached the lower end of the small intestine, most of the food that will dissolve has been dissolved and absorbed through the walls into the blood stream. The part of the food that has not digested and a good deal of water that is mixed with it are pushed on into the large intestine.

WHAT HAPPENS TO THE UNDIGESTED PART OF THE FOOD? The large intestine is much shorter than the small intestine, but it has a larger diameter. Here the extra water is absorbed from the worked-over food, so that the body will not lose it. Then the undigested food is gradually pushed along toward the lower end of the large intestine and stored. From time to time, it is passed out of the body.

The material that is stored in the large intestine contains large numbers of bacteria. These bacteria are usually quite harmless to the body. In fact, some animals use them to help digest their food. However, these bacteria live on the remains of the food and cause chemical changes in it that are somewhat like decay. It is usually best, therefore, that the materials left over from digestion should not be kept in the large intestine for more than a day.

HOW CAN WE HELP OUR DIGESTIVE SYSTEMS? Probably the best help you can give your digestive system is to keep yourself happy and interested in life. Worry, anger, and unhappiness in some way influence the work of the digestive system and may cause actual illness. It is especially harmful to be unhappy and tense at meal-time. These emotional disturbances slow down the usual secretion and movements of the digestive organs. Another thing that often upsets the digestive organs is to engage in vigorous physical activity immediately after a heavy meal. When this is done, the body sends to the muscles the blood that should be going to the digestive organs.

You can also help your digestive organs by the way you eat. The digestive chemicals can dissolve small particles much more quickly than large ones. To chew food well requires that you form correct habits of eating and that you keep your teeth in condition to do their work effec-

tively. After your permanent set of teeth has grown, you cannot get new ones to take their place. The use and appearance of your teeth is so important that you should take better care of them than you would of jewels.

Unfortunately, the teeth are likely to decay. Scientists have never found out just what causes tooth decay. They do know that there is less decay when we eat a good healthy diet, exercise the teeth and jaws by chewing firm foods, and keep the teeth clean. Eating much sugar and candy seems to make the teeth decay more rapidly.

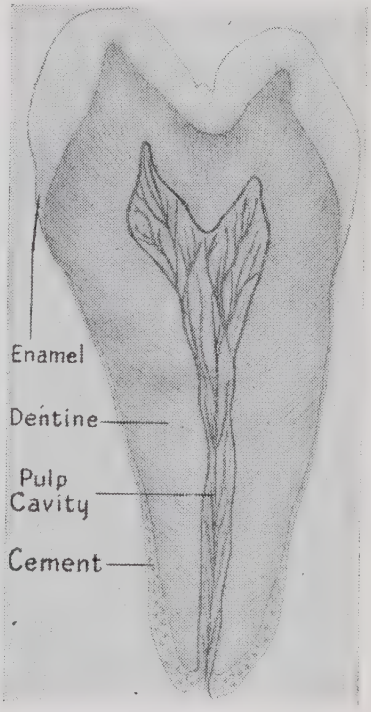


FIG. 293. The structure of a tooth. A hard coating of *enamel* protects the softer *dentine*.

Holes, or *cavities*, in teeth can be filled by a dentist, and the decay will usually stop. A dentist can also find cavities that we cannot see for ourselves, especially if he takes X-ray pictures of the parts of the teeth that touch each other. It is up to each one of us to keep his teeth clean and to have a dentist inspect them every few months.

Still another way to help your digestive system is to choose your food with a reasonable amount of care. A healthy diet contains plenty of fresh fruits and vegetables, whole-wheat foods, and milk. As you probably remember, these foods contain minerals for the teeth (and bones) as well as vitamins that help build the minerals into good sound teeth and bones. Vitamins also help to keep the lining of the food tube in good condition.

Fruits and vegetables help in two other ways. They give

the teeth and jaws exercise that seems to help in keeping the teeth and gums in good condition. They also contain a rather large amount of fibers and other indigestible materials. These materials fill up the large intestine and help to make the intestine empty itself regularly. Whole-wheat foods are helpful in the same way.

Self-Testing Exercises

1. Give three reasons why the small intestine can absorb digested food quite rapidly.
2. How do digested carbohydrates get into the blood? Digested fats?
3. Tell briefly, but accurately, what happens to a piece of whole-wheat bread, (*a*) in the mouth, (*b*) in the stomach, (*c*) in the small intestine, and (*d*) in the large intestine. Remember that the bread contains all three classes of food material and some parts that are not digestible.
4. What happens to any food that does not dissolve?
5. State three important ways of keeping your digestive system in good condition.

Problems to Solve

1. Chew a dry cracker for a long time. Notice carefully to see if there is a change in its taste. If so, explain.
2. How long would the small intestine need to be if it were smooth instead of being lined with folds and villi? Assume that folds and villi increase the area of the entire small intestine to eight times what it would be if it were smooth on the inside.
3. Can you show that the flow of the saliva into the mouth is influenced by what you think?
4. Read in physiology or other reference books to find what duties the liver has besides the secreting of bile.
5. What is peculiar about the circulation of blood to the liver? Study diagrams of the circulatory system to solve this problem.
6. How might a quarrel at meal-time cause indigestion?

Problem 5:

HOW DOES YOUR BLOOD GET OXYGEN AND GET RID OF CARBON DIOXIDE?

You have known for a long time that people and animals must have air. Now you know why air keeps you alive. Oxygen from the air oxidizes the food in your cells and turns loose the energy the cells need. And you know, too, that we breathe out carbon dioxide. Now you know where the carbon dioxide is made. It is made in the cells where the carbon of our food unites with oxygen. From the cells it diffuses into the blood and goes to the lungs.

You know that air goes into your lungs when you breathe in, or *inhale*, and that carbon-dioxide gas goes out when you breathe out, or *exhale*. Do you know how your lungs are constructed to let all the blood in your body exchange its carbon dioxide for oxygen each minute that you live?

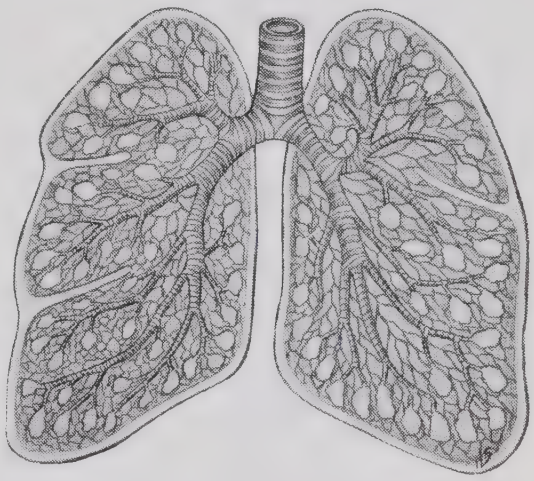


Fig. 294. This drawing shows how the windpipe divides to go to each lung and how the two branches divide into countless little branches to carry air to every part of the lungs.

What is the structure of the respiratory system? To understand how the breathing system works, you will need to have a clear idea of how it is made. If at all possible, you should examine some real lungs.

Experiment 49. *What Is the Nature of the Lungs?* (*a*) Examine the lungs of a sheep. These organs are about the size of a person's lungs. Find a rather large tube, the *windpipe*, or *trachea*, connected to both lungs. This tube will sometimes have been split open by meat inspectors. If so, you will be able to

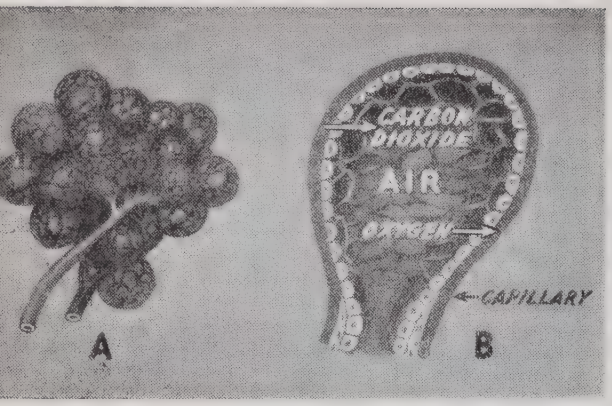


FIG. 295. Drawing A shows a group of air sacs. Notice how they are covered by a network of capillaries. Drawing B shows one air sac as it would look if split open. Of course, both drawings are highly magnified.

see many little tubes leading into the lungs from the lower part of the windpipe. You will also be able to see the many rings of cartilage that held the windpipe open. (See Figure 296.) Feel the lungs with your fingers. Are they firm and heavy or light and spongy?

b) Get a rather large glass tube about a foot long and round the edges by holding the end in a gas flame until they are no longer sharp. When the tube is cool, push it into one of the bronchial tubes and blow until the part of the lung connected to that bronchial tube is blown full of air. Its appearance will change and become more like that of a natural lung. Release the air and notice what happens to the lung. By blowing air into the lung and then releasing the air you can imitate the movements of the lungs during breathing.

With a sharp knife cut off a bit of lung that has been blown up. Look carefully at the cut edge. Can you see some of the very tiny bronchial tubes? Can you find, also, some almost invisible air bubbles? These tiny bubbles are the *air sacs* at the ends of the bronchial tubes (Figure 295).

Let us follow some air as you breathe it in. Figure 296 will help you get a clear picture of its journey. First the air goes into your nose. The *nasal passages* from your nostrils to your throat are quite narrow and irregular, made so partly by the *turbinate bones*. Also, the walls of the passages are moist and warm. If the air is not clean, much of the dust is caught in the moisture on the sides of the nasal passages. The air is also warmed as it passes back to the throat. In the throat the air goes down across

the food tube and enters an opening in front of the esophagus, called the *glottis*. Just above the glottis is a little "flap," called the *epiglottis*. This flap covers the glottis when we swallow so that no food or water will go down into the lungs.

The air next enters the voice-box, or *larynx*. You call the front side of the larynx your "Adam's apple." In the larynx the air goes through a narrow slit between two bands of tissue that vibrate to make the sounds of the voice. These bands are the *vocal cords*. From the larynx the air goes down a rather large tube, the windpipe or *trachea*. About six inches below the "Adam's apple," the air is separated into two parts by the *bronchial tubes*. One part goes into a bronchial tube that enters the right lung, and the other part of the air goes into a bronchial tube that enters the left lung.

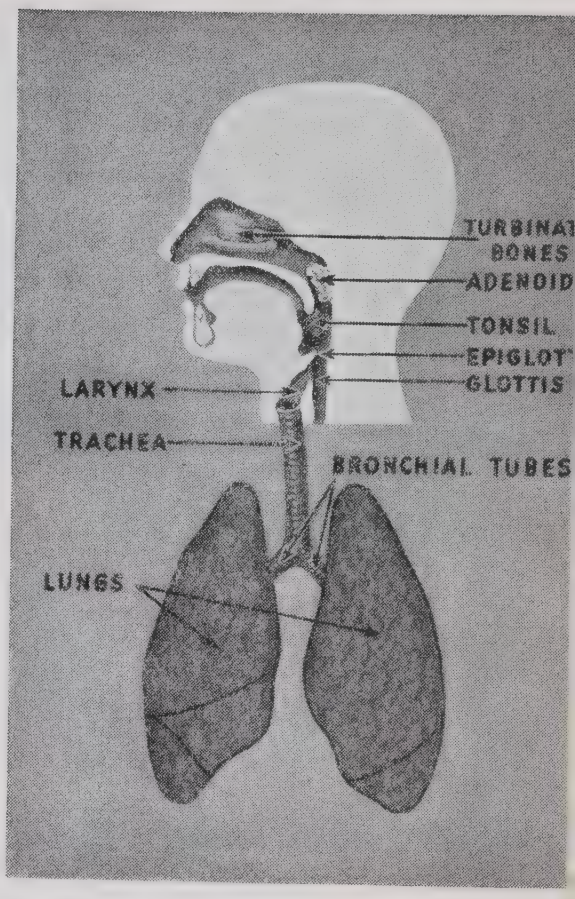


FIG. 296. The respiratory system

Once inside the lungs, the air runs into smaller and smaller bronchial tubes that fork like the branches of a tree. These branches become smaller and smaller until they reach into every part of the lungs. At the ends of the very finest bronchial tubes, the air goes into many tiny cup-shaped cavities arranged all around the tubes, somewhat like grapes on a stem (Figure 295A). These tiny cavities are the *air sacs*. Here only the thin wall of the air sac and the thin wall of a capillary lie between the blood and the air. Therefore the oxygen is easily absorbed through the walls into the blood.

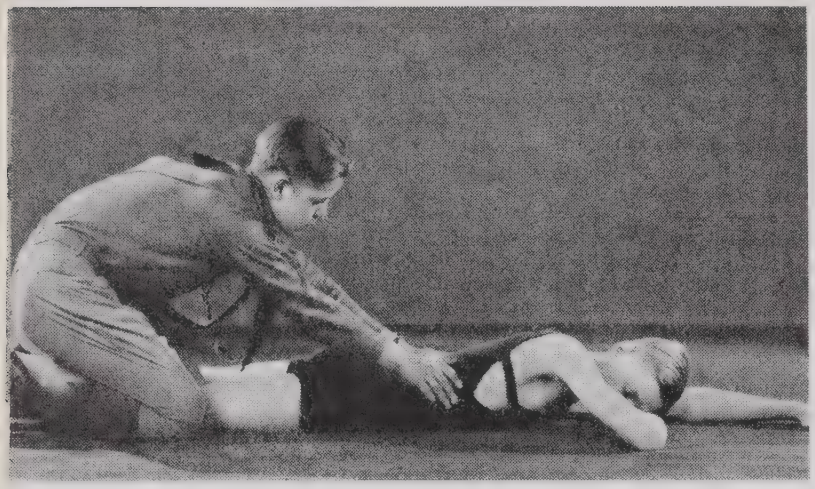


FIG. 297. Can you apply *artificial respiration* to a person who has been drowned or in some other way suffocated? This picture shows the correct position for beginning. The palms of the hands are placed on the short ribs across the small of the back. The patient's head rests on his arm to keep his nose and mouth free. Now study Figure 298.

The two lungs fill almost the whole chest cavity except the part filled by the heart and windpipe. The lungs are very light, spongy organs because they contain so many bronchial tubes and air sacs. Blood vessels run all through the lungs to carry blood to each air sac and back again to the heart.

No one has been able to count all the air sacs in a lung. However, one careful scientist has estimated that the lungs of a grown person contain 600,000,000 air sacs. If the linings of all these sacs could be formed into a single sheet of material, there would be enough to cover the walls of a room fifteen feet wide, twenty feet long, and ten feet high. Can you see why so much lining is useful in the lungs?

HOW DOES THE BLOOD EXCHANGE CARBON DIOXIDE FOR OXYGEN? Figure 295 will help you understand what happens in the walls of the air sacs. The blood that enters the wall of an air sac contains much dissolved carbon dioxide. The air in the air sac contains very little of this gas. Carbon dioxide thus passes from the blood into the air sac. At the same time there is much oxygen in the air sac and little in the blood. The lining of the air sac is always moist. You know that gases can dissolve in liquids.

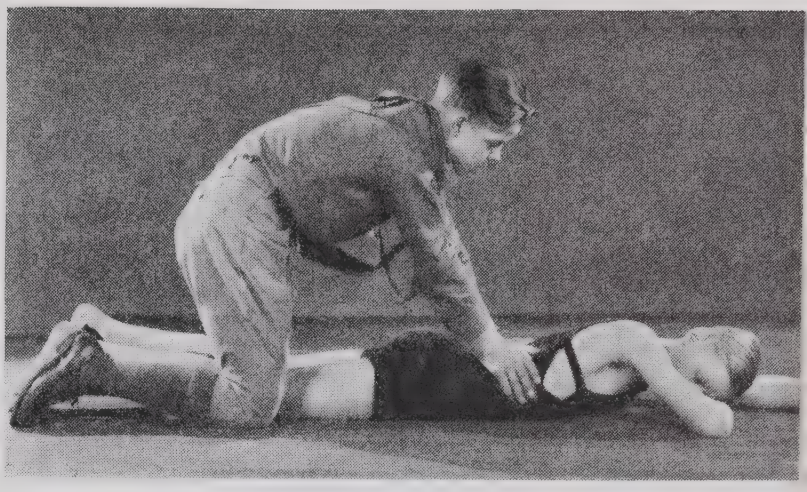


FIG. 298. The operator bends his body forward, letting his weight fall on his wrists. This weight squeezes the victim's chest and thus decreases its size, expelling the air. Then the operator swings back to first position, the chest expands, and air goes in. These movements should be kept up twelve to fourteen times a minute for an hour or more.

The oxygen from the air dissolves in the moisture in the lining of the air sac and diffuses into the blood.

A moment after some air enters an air sac, it has lost some of its oxygen and has received carbon dioxide in place of the oxygen. The carbon dioxide must be gotten out of all the air sacs, and more oxygen must be gotten in to keep diffusion going on as it should. Of course, it is your breathing, or *respiration*, that gets the used air out of the air sacs in your lungs and takes in fresh air. This is caused by the breathing movements made by the chest. Fresh air is brought into the lungs when you breathe in, or inhale, and used air is forced out when you breathe out, or exhale.

Some people think that all the oxygen is taken out of the air in the lungs and that what we breathe out is pure

TABLE 3. HOW THE AIR IS CHANGED IN OUR LUNGS

Gases in the Air	Amount in Air Breathed In	Amount in Air Breathed Out
Nitrogen	79.0%	79.0%
Oxygen	20.0	16.0
Carbon dioxide	0.04	4.0
Other gases	0.96	1.0
Moisture	Variable amount	Almost saturated

carbon dioxide. Table 3 shows that these ideas are incorrect. The air is mostly nitrogen. This is not used in the body; so its amount does not change as the air goes into and out of the lungs. But the air does change in three ways while it is in the lungs: (1) About one-fourth of the oxygen in the air goes into the blood. (2) An almost equal amount of carbon dioxide comes out of the blood into the air. (3) Moisture from the linings of the air passages and air sacs evaporates until the air is saturated.

FIG. 299. In certain kinds of work men and women wear or should wear masks to protect their lungs from dust.

HOW CAN YOU KEEP YOUR RESPIRATORY SYSTEM IN GOOD CONDITION? Like other parts of your body, the respiratory system really takes care of itself if you give it a fair chance. The breathing muscles are controlled automatically by nerve messages, so that you breathe at the correct rate to keep fresh air in the air sacs. The correct rate of breathing for a normal, healthy person of your age is about twenty-two breaths per minute.

One way in which the respiratory system protects itself is by the structure of the air passages. The linings of the air passages are covered with microscopic living hairs, called *cilia*, that move back and forth. The movements of these cilia sweep dust and other useless materials up and out of the air passages.

The most important way to help your respiratory system is to keep yourself in good physical condition by getting enough rest, the right kind of food, fresh air, and a

reasonable amount of exercise. Such diseases as colds, pneumonia, and tuberculosis, that attack the respiratory system, are much less likely to get started in persons who are in the best of condition. Of course, you should also as far as possible avoid the germs that attack the respiratory organs. You will learn more about how to avoid these disease germs in the next unit.

Exercise is of great value to the lungs because it makes us breathe deeply and use the air sacs in all parts of the lungs. At all times we should breathe as little dust as possible because dust is likely to irritate the delicate linings of the air passages. Then germs can attack these linings more easily. Some kinds of dust, such as the dust from rock that contains quartz, cause serious disease in the lungs. People who must work continually in any kind of thick dust should protect themselves by wearing masks to strain the air.

Self-Testing Exercises

1. Tell the story of an oxygen molecule that goes from an air sac into the blood. You may wish to draw a simple diagram to illustrate your story.

2. Do Exercise 1 for a carbon-dioxide molecule that comes back from a cell in the blood.

3. How is the air you breathe out different from the air you breathe in?

4. What do you think is the correct way to take care of your breathing organs?

Problems to Solve

1. Fill in the story of the oxygen molecule in Self-Testing Exercise 1 from the time it entered the blood until it came back from the cell as a part of the carbon-dioxide molecule in Self-Testing Exercise 2.

2. Make as long a list as you can of the ways in which the lungs are fitted to do their work well.

3. Make a model to show how the diaphragm helps fill the lungs with air. Use a bell-jar with a neck as shown in Figure 300, or a large bottle without a bottom. Fit the neck with a stopper, glass tube, and thin rubber balloon. Use a piece of old inner-tire tube for the artificial diaphragm. Be sure to tie it so that no air can escape around the lower edge of the jar. Push in and pull out on the "diaphragm." What does the balloon do? Explain and compare the action of your model with the action of the human chest and lungs.

FIG. 300

4. How much air can you breathe out of your lungs? Fill a one-gallon glass jug with water and turn it upside down in a large pan that contains about three inches of water. Fill your lungs and breathe out through a rubber tube that extends up into the jug of water. Measure the amount of air you breathe into the jug. Compare your lung capacity with that of other members of your class.

5. How fast do you breathe under ordinary circumstances after exercise? Choose a partner to count your breaths for a minute after you have been resting and after exercise. Then count his and compare results.

6. How can you best help a person breathe when he has stopped breathing because of an accident? Read about artificial respiration in reference books and, if possible, practice artificial respiration with a friend. If correctly done, the person who is pretending to be injured need not use his breathing muscles while you carry on artificial respiration.

7. Do you think that you use more oxygen during one hour of the day or during one hour of the night? Give a reason for your answer.

8. Find out what a pulmotor is and how it is used in cases of drowning and suffocation.

9. Why must adenoids and tonsils sometimes be removed?

Problem 6:

HOW DOES THE BODY GET RID OF ITS NITROGEN WASTES?

OUR BODIES must get rid of three main kinds of used materials: undigested foods, oxidized carbon or carbon dioxide, and nitrogen wastes from the protein used by our bodies. You know that the lower part of the large intestine passes the undigested food out of the body. You have also learned how the gas, carbon dioxide, gets out of the blood in the lungs and how we breathe it out of our bodies.

The nitrogen wastes of the body are largely in the form of a white chemical compound, called *urea*. Being a solid material, the urea cannot leave the blood in the lungs. When it is ready to leave the body, this compound is dissolved in the liquid part of the blood as salt is dissolved in water. It is removed from the blood and passed out of the body by a special system of organs that make up what is called the *urinary system*, or the kidney system (Figure 301).

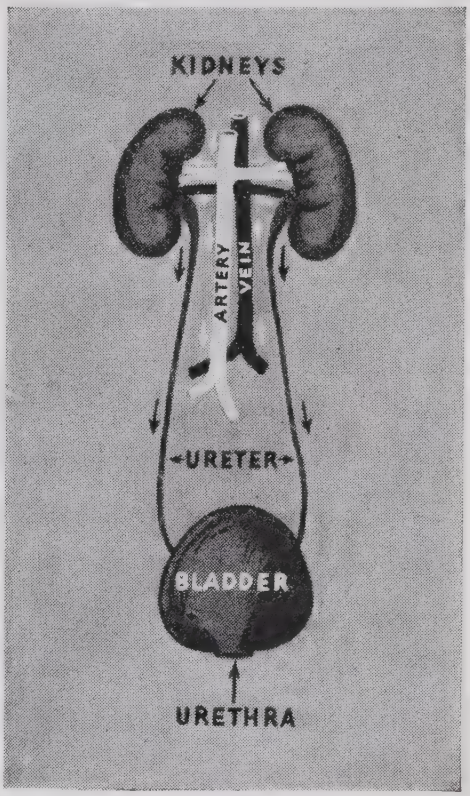


FIG. 301. The kidney system

HOW IS THE KIDNEY SYSTEM CONSTRUCTED TO DO ITS WORK? Some people have a vague idea that the kidneys are connected with the digestive system. But this idea is not correct. The two kidneys themselves are behind the stomach and liver, one kidney on each side of the backbone. Their position in the body is clearly shown in Figure 277, page 363.

Since the kidneys must remove wastes from the blood, each one has a large artery leading into it and a large vein leading out of it. The kidneys remove dissolved urea and other chemicals from the blood together with some water. This mixture is the liquid called *urine*. From each kidney a tube, called *ureter*, leads down to the very lowest part of the abdominal cavity. There the urine is stored in a muscular sac, called the *urinary bladder*. From time to time the urine is discharged from the body through a third tube, called the *urethra*.

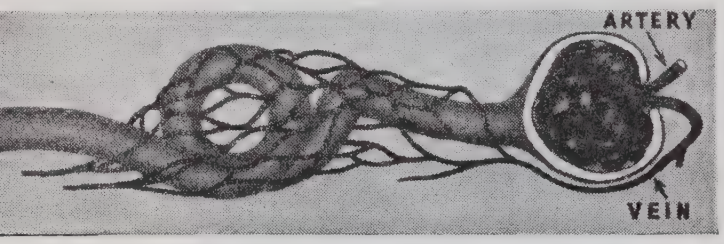


FIG. 302. A kidney tubule and its capillaries

The kidneys are, of course, the really important parts of the urinary system. A person can live with only one-half of one kidney, but if both are removed or stop working, death is sure to follow. Each kidney of a grown person is composed of about a million tiny tubes, called *tubules*, each one very closely connected with a network of capillaries.

Figure 302 shows a single kidney tubule and some of its capillaries. Water containing dissolved waste materials filters out of the blood in the capillaries at the globe-like end of the tubule. In some way that is not yet understood, the cells along the middle part of the tubule take some of the water out of the urine and return it to the blood. If the body does not have plenty of water, no more than is necessary is lost through the kidneys. In this way the kidneys act as a kind of water regulator for the body.

Besides removing the nitrogen wastes from the blood, the kidneys have a large part in regulating the different materials in the blood. Whenever there is too much sugar,

salt, or water in the blood, the kidneys remove the extra substance and thus help keep the correct amounts of these substances in the blood.

If kidney or bladder disease develops, it usually does so late in life when the body begins to "wear out." However, many doctors believe that we can help to avoid trouble by taking care of our kidneys. Drinking sufficient water (not less than six to eight glasses a day) gives the kidneys an abundant amount in which to dissolve the waste materials. By keeping in good physical condition and by avoiding overeating and the excessive use of alcoholic drinks, we can protect our kidneys from overwork.

Sometimes disease germs or their poisons injure the kidneys. One of the main reasons for having a doctor to care for us during illness is to avoid unnecessary damage to the kidneys.

Self-Testing Exercises

1. Why are the kidneys a necessary part of the body?
2. Tell briefly how the kidneys do their work.
3. How and why are the kidneys connected to the bladder?

LOOKING BACK AT UNIT 8

1. Use about two pages to tell the really important ideas about how the body works. Choose your ideas carefully. Then write them down in a connected way, so that a person reading your summary can understand about the body.

2. Show in some way that you know the meaning of each of the following terms.

vein	*gland*	*alimentary canal*	*artery*
urea	*cartilage*	*bronchial tubes*	*diffusion*
villus	*capillary*	*diaphragm*	*ureter*
tendon	*ligament*	*gastric juice*	*corpuscle*
vertebra	*oxidation*	*system (of organs)*	*cilia*

ADDITIONAL EXERCISES

1. Make a list of the changes that take place in your body when you exercise vigorously. For example, one change is, "*The heart beats more rapidly.*"

2. How many uses of water in the body can you think of?

3. Read in reference books about how different animals, such as fish and insects, get oxygen.

4. Shake up a quart of clear limewater with air. Then put a gold fish in the water. How does the water change? Explain what happens.

5. Find in reference books what the ductless, or *endocrine*, glands do for the body. Some of these glands are the thyroid gland, adrenal glands, and pancreas.

6. Look in the *World Almanac* or some similar book of facts for the most common causes of death. Which set of organs seems to wear out most often? (Cancer is not a disease of any one set of organs.)

7. Compare the working of the heart with the working of a water pump. Refer to pages 374-376.

8. Plan and try an experiment to find out if a candle will burn in the air you breathe out.

9. Read in reference books to find what William Harvey discovered about the blood and how he discovered it.

FIG. 303. Edward Jenner, an English doctor, discovered the method of preventing smallpox, called vaccination, in 1796. It is said that the first person to be vaccinated by Dr. Jenner was his eight-year-old son. This experiment was successful, and man had discovered another way to fight disease. In this unit you will learn how vaccination keeps a person from having smallpox. You will also learn how other diseases are caused, how many of them can be prevented, and how you can help your body keep itself free of disease.

UNIT NINE

UNIT 9

HOW CAN YOU HELP YOUR BODY FIGHT DISEASE?

INTRODUCTORY EXERCISES

1. Make a list of diseases that you have had. Which were the kind you could "catch," and which were not?

*2. What are bacteria?

3. (*a*) What does your city or community do to keep its people healthy? (Some cities sprinkle the streets, see that garbage is kept in cans where flies cannot get at it, have health clinics, etc.) What should your community do that it does not do?

b) Answer these same questions for your school.

4. Make a list of the things you can do to help keep yourself and your family healthy.

5. What are germs? Are all germs dangerous? What is a "germ disease"?

6. How do germs harm a person's body?

7. What vaccinations, or "shots," have you had? How did these treatments keep you from having the diseases for which you were being treated?

8. Perhaps you have heard insects called "carriers of disease." List the insect-carried diseases that you know. Which of these diseases occur in your community?

9. Explain how these two expressions are alike:

a) "An ounce of prevention is worth a pound of cure."

b) "Preventive medicine is being looked upon more and more as the gateway to health."

FIG. 304. The Indian medicine-man is treating a patient by holding an apple stuck full of feathers on his neck. The other medicine-man is selling a patent medicine, which is useless and perhaps harmful. Instead of these superstitious remedies and patent medicines reliable doctors use treatments that scientists have proved to be helpful in fighting disease. (Ewing Galloway, N. Y.)

LOOKING AHEAD TO UNIT 9

DID YOU ever have someone say to you, "Good-morning. How do you feel today?" Perhaps you replied, "Good-morning. I feel like a *million dollars*." That was a slang way of saying that your body was working well. Probably you did feel like a million dollars so far as your health was concerned. Certainly no one would take a million dollars for his health. All the money in the world would be of little value to a person if he were sick all of the time.

People have done and still do many strange things to try to keep their health or to regain it if they have lost it. In times of long ago people were so ignorant of how the human body works that they did not know what made them sick or what to do to get well. If we compare some ancient ways of curing diseases with some modern methods, we can appreciate more fully the progress that science has made in keeping people healthy.

Suppose you were a member of some very primitive tribe of people and you became ill. How would the tribal witch-doctor try to cure you? There might be ceremonial dances with the loud beating of tom-toms to scare away the evil spirits that were supposed to cause the disease. If this failed, the witch-doctor might give you a necklace made of animal's teeth. He would tell you that this charm, if worn, would drive the disease away. He might even sew an animal's tooth, some burned feathers, a few bones, and some ashes into a sack made of frog skin. He would tell you to wear this as a protection against the disease. Of course, you would not be willing to trust these foolish kinds of remedies.

However, people today do things that are just as foolish. They buy and use treatments that are worthless or even harmful. Look through certain magazines, and you will see many such false cures advertised. Some of them claim to cure gallstones; others, stomach and intestinal diseases; and some of the most extreme even claim to cure the deadly disease, cancer. These advertisements are harmful in two ways: (1) They take the patient's money and give him no real benefit in return; and (2) they prevent or delay the getting of advice from some honest, well-trained doctor.

Strangely enough, some people take such "quack" treatments and actually get well. But they do not get well because of these so-called cures; they get well in spite of them. Their bodies are strong enough to fight the diseases and overcome the "treatment," too.

In his long search for health, man has learned more and more about the causes of diseases and how to help his body fight them. What are some of the modern ways of keeping healthy and of treating diseases? All of us

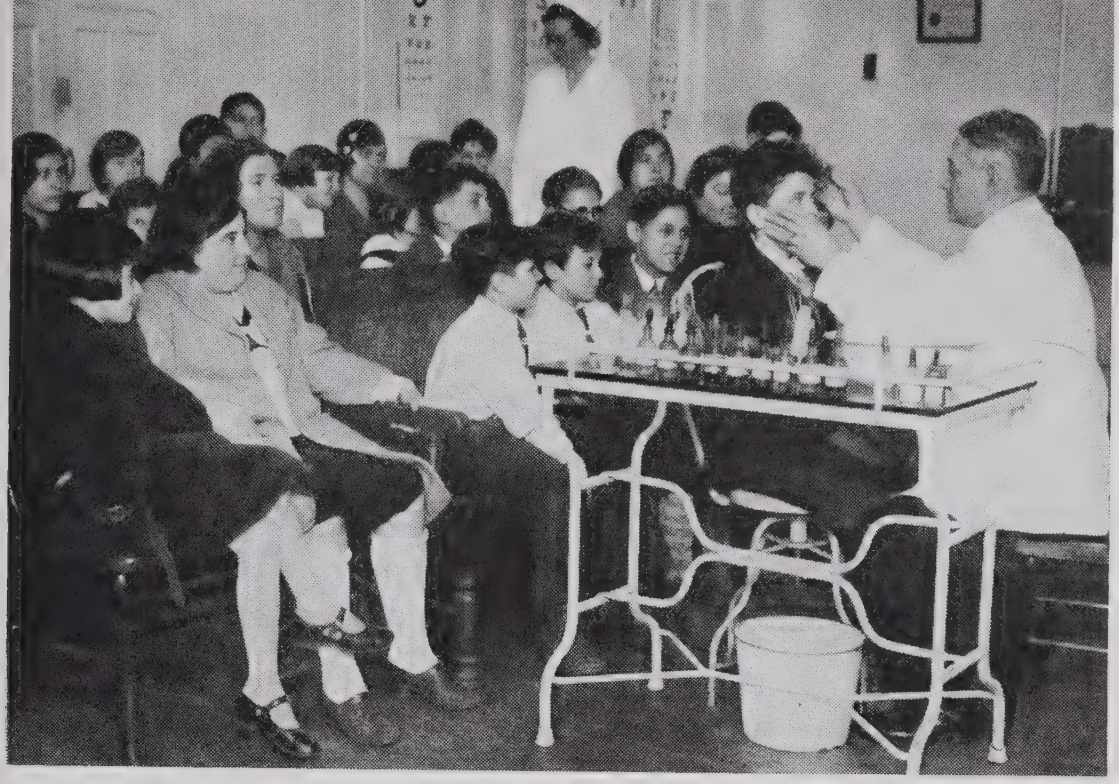


FIG. 305. Doctors make many tests to find whether people are in good physical condition. In this health clinic the doctor is examining the eyes of all the children in a school class. (Ewing Galloway, N. Y.)

should have our bodies examined regularly once every year or two, even though we are not sick. A good doctor, with his scientific tests, can often detect diseases before we feel ill. Then he can begin treatment at once and help our bodies to overcome the disease more easily. Perhaps your school gives medical examinations each year to see that you are in good physical condition.

Have you ever been to a health *clinic?* Everything was spotlessly clean. The walls were white, and the windows let in plenty of sunshine. The doctor's instruments were either steamed or dipped in alcohol to kill any germs that might be on them. The doctors examined your nose and throat to see that they were in good condition. They looked at some of your blood through a microscope to find whether it contained the right number of red and white corpuscles. They even listened to your heart beat with an instrument called a *stethoscope.* If you were ill, their careful tests showed them what was wrong with your body and helped them select the best treatment for you.

Of course, this is not the whole story of modern medical science. But it does show you how much more scientific our methods are than those of primitive people and of false doctors today who advertise cures for everything.

Now let us examine a few of the important health problems everyone must face, and let us learn how to face them intelligently. How can we help keep our bodies healthy, so that they can resist diseases? How can we keep germs from getting into our bodies? How can we coöperate with doctors and other health authorities when we take a disease? How can we make our community a more healthful place in which to live? These are the important health problems that everyone meets. This unit will tell you much about them.

Problem 1: WHAT ARE DISEASE GERMS?

Almost two hundred and fifty years ago, Anton van Leeuwenhoek, a Dutch scientist, discovered the existence of plants and animals so small that they could be seen only through a microscope. At that time people believed that these tiny living things just grew from the substances in which they were found; that is, they thought spoiled meat juice, garbage, and sewage produced microscopic plants and animals.

Eighty years after Leeuwenhoek's time a wonderful new discovery was made by Lazaro Spallanzani, an Italian scientist. He actually saw one of these tiny one-celled *organisms* divide into two organisms. Then he saw the two organisms divide into four, etc. In this way he learned that these tiny plants and animals can multiply and produce countless other plants and animals like themselves.

But it was nearly a hundred years before three great scientists, Louis Pasteur, a Frenchman, Robert Koch, a

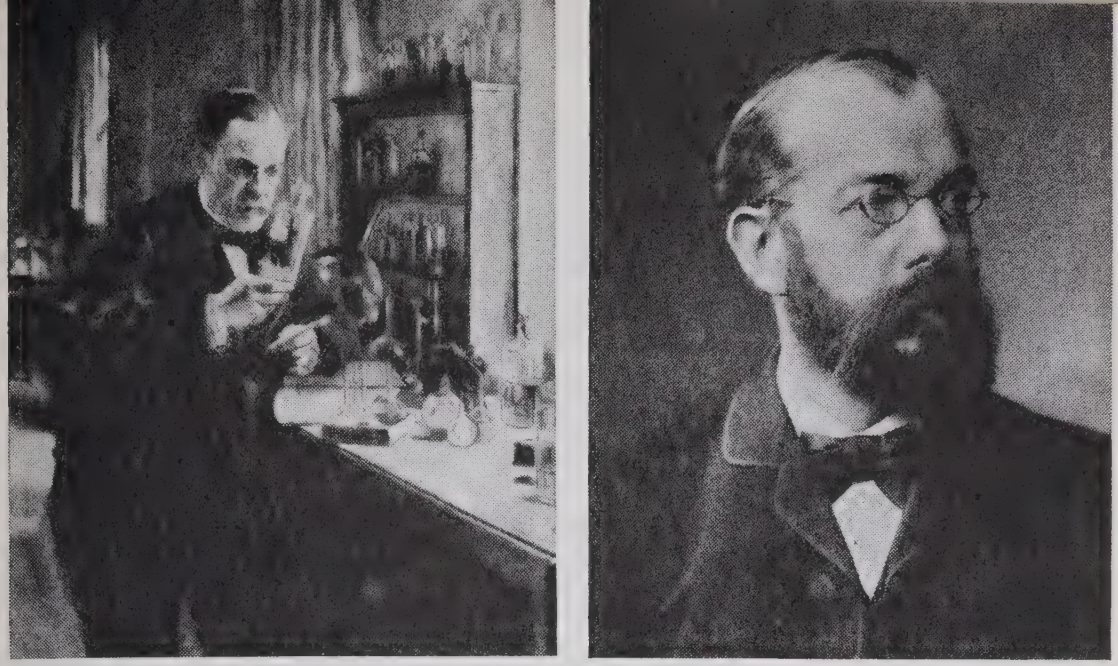


FIG. 306. Louis Pasteur, shown here in his laboratory, and Robert Koch are two of the great scientists whose discoveries have helped in the work of fighting disease.

German, and Joseph Lister, an Englishman, showed that certain diseases are caused by tiny organisms in our bodies. The final proof that many diseases are caused by microscopic plants and animals was worked out by Koch in 1876. These scientists also proved that if these organisms are not allowed to develop inside the body, a person does not have the diseases they cause. Therefore, the problems of modern medical practice are: (1) to keep these tiny living things, called *germs*, from getting into the body; (2) to know how to kill germs without harming the body; or (3) to help the body kill germs and repair itself.

Of course, not all diseases are caused by germs. When some organ of the body fails to do its work, we say the disease is *organic*. Heart trouble, caused by the improper working of the heart, is an organic disease. However, in this unit you will study chiefly the diseases that are caused by germs.

Self-Testing Exercises

1. What is a disease germ?
2. What is the difference between organic diseases and germ diseases? Give an example of each kind of disease.

FIG. 307. In all parts of the world men and women called *bacteriologists* spend their lives searching for bacteria that are still unknown and for methods of fighting those that are known. You may find it interesting to watch in newspapers and magazines for news of important discoveries about disease germs.

WHAT ARE PLANT GERMS LIKE? Do you know that many tiny plants actually live in our bodies? Some of these organisms do us little or no harm, while others cause serious diseases. Many of the microscopic plants that cause diseases are known as *bacteria*. Bacteria are one-celled plants of various sizes and shapes. Each tiny plant, or *bacterium*, is so small that from 5000 to 50,000 of them are required to make a row one inch long. Some bacteria are so small that a million of them could be placed on top of an ordinary pin head. Yet, if the conditions are right, a single one of these bacteria may grow and make more bacteria until there are enough of them to kill a man or even an army of men.

Let us examine some bacteria to see what they are really like. There are thousands of different kinds; so their classification is a rather difficult matter even for the *bacteriologist*. However, most bacteria may be recognized by the effects that they produce while they are growing

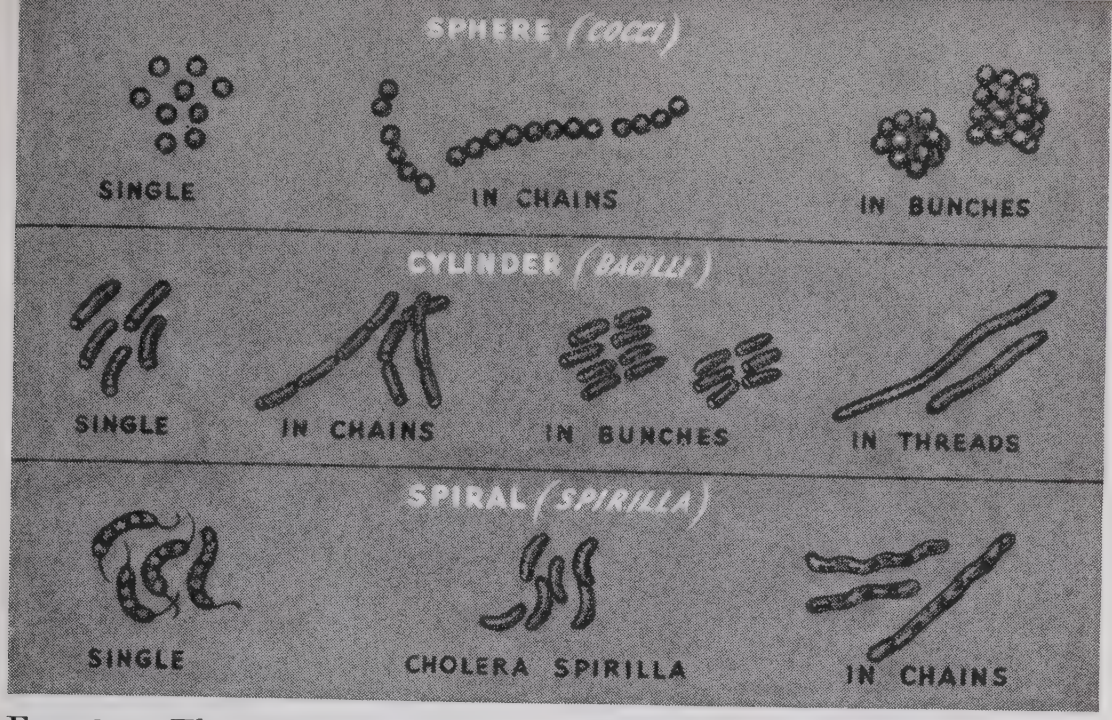


FIG. 308. The three general groups of bacteria. When cocci are in chains (top center), they are known as *streptococci*.

and by their shapes. Three groups of bacteria are commonly recognized.

Suppose that a bacteriologist is letting you examine some of these plants under a very powerful microscope. You find some tiny, ball-shaped cells. These cells may be separate from each other, or they may be in long chains or in bunches (Figure 308). "Those are *cocci*," says the bacteriologist. "Scarlet fever and pneumonia are caused by the *coccus* type of bacteria."

You put another slide under the microscope and focus the instrument. This time you see many peculiar cylinder-shaped cells. Some are attached end to end like links of sausages; others are grouped in small bunches or masses.

"These are not cocci, for they are shaped differently," you say.

"No," he tells you, "they are *bacilli*. Perhaps you have known people who have had typhoid fever or tuberculosis. The germs of these diseases are of the bacillus type."

You examine another slide under the microscope. This time you see corkscrew-shaped cells. Some are by themselves, and others are joined together to form spiral chains.

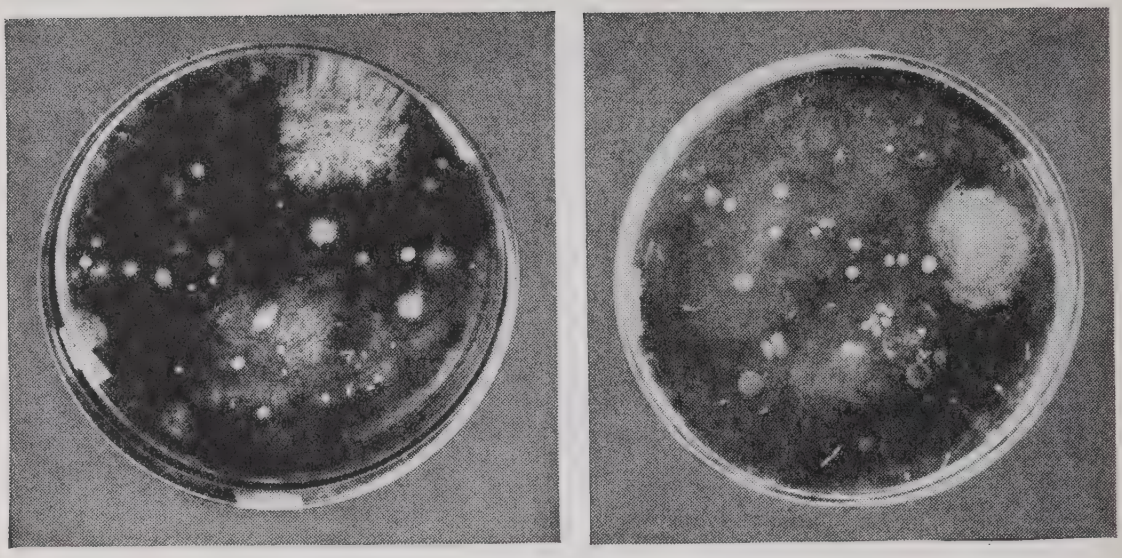


FIG. 309. The culture dish at the left was uncovered for twenty minutes. The large spot is a mold growth; the small spots are colonies of bacteria. The other culture dish also shows spots of bacteria that grew after fingers had been rubbed across the surface of the gelatin.

"These bacteria are shaped like springs or spirals. They must be another kind," you say.

"They are another kind," answers your friend. "You already have the name, *spirilla*, from their spiral shape. Cholera is caused by the spirillum type of bacteria."

EXPERIMENT 50. *Where Are Bacteria Found?* Boil six shallow dishes with tight covers for half an hour to sterilize them. While the dishes are boiling, mix about five ounces of unflavored gelatin in a quart of water. Add a pinch of salt and one-half ounce of beef extract or sugar. Heat the mixture until the gelatin is dissolved.

Pour enough of the gelatin mixture into each dish to cover the bottom. Then set the covered dishes in a covered steamer or a steam sterilizer. Keep them in live steam for an hour. When the gelatin has hardened, treat the six dishes as follows:

a) Leave one dish open to the air for about fifteen minutes (after the room has just been swept, and dust is in the air); then cover the dish.

b) Scrape around your teeth with a toothpick and rub the

toothpick over the surface of the gelatin in another dish; then cover it. Label each dish so that they will not become mixed.

c) Put a few drops of unclean milk into another dish; then cover the dish.

d) Rub your fingers across the surface of a dish; then cover.

e) Keep another dish of clean gelatin tightly closed.

Keep the dishes at room temperature (or slightly warmer) for several days. Watch for pink, yellow, or white spots on the gelatin. These will be colonies of bacteria. (Remember that a single bacterium is too small to be seen without a microscope.) Explain what happens in each case. If your work was carefully done, colonies of bacteria did not appear in dish *e*. Why not?

In Experiment 50 bacteria probably grew in each of the dishes except the one that was kept tightly closed. This might lead you to believe that bacteria are almost everywhere. And such is the case. Scientists have carried dishes of gelatin up into the stratosphere, to the tops of highest mountains, and deep into mines. In every place that they have tested they have found bacteria present.

However, most and perhaps all the bacteria you caught in your culture dishes were harmless. Many bacteria in the air, water, and soil are helpful because they use the bodies of dead plants and animals for food and thus help get rid of them. Others help plants by taking nitrogen from the air and making it into useful compounds, as you learned in *Science Problems, Book One.* A few of the bacteria found in soil and water and other kinds that live in the bodies of men and animals make us sick when they get into our bodies. These kinds of bacteria form one group of disease germs.

Bacteria are not the only plants that cause diseases. Certain kinds of yeasts, one-celled plants that you have studied, may get into broken places in the skin and cause

sores. Tiny mold-like plants cause a skin disease known as "athlete's foot." Parts of these small plants break off from plants that are on the foot of a person who has the disease. Then, when another person steps upon these plants, they lodge in moist places upon the skin of that person's foot and grow, causing him to develop the disease.

Self-Testing Exercises

1. Are all bacteria harmful? Explain.

2. (*a*) Scarlet fever is caused by *streptococcus* germs. From their name, what shape do you think they have?

b) Leeuwenhoek wrote a paper in 1683 describing a tiny living thing that he thought was an animal. Later, other scientists found it living commonly in saliva. They gave it the name *Spirillum sputigenum*. What was its shape?

FIG. 310. Tuberculosis germ, magnified thousands of times. These are germs of the bacillus type.

3. Name some diseases that are caused by bacteria.

4. Which of these statements is correct? Explain your answer.

a) *All bacterial diseases are germ diseases.*

b) *All germ diseases are bacterial diseases.*

WHAT ARE ANIMAL GERMS LIKE? Some kinds of one-celled animals may get into the body and cause diseases. But there are not nearly so many different kinds of one-celled animal germs as there are one-celled plant germs. However, they have many different shapes, and they affect different parts of the body. Amoebic dysentery, malarial fever, and African sleeping sickness are diseases known to be caused by certain one-celled animals.

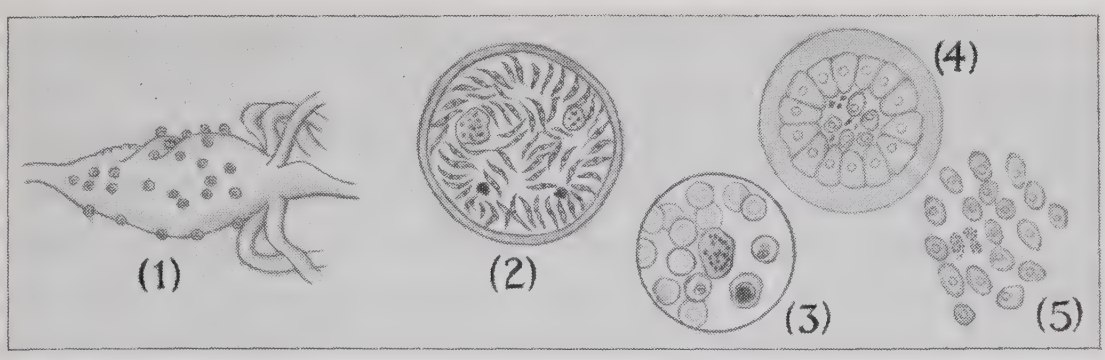


FIG. 311. The development of the one-celled animal germs that cause malarial fever is shown in these pictures. (1) The germs begin in small growths on the outside of the stomach of a mosquito that has bitten some person ill with the fever. (2) In each of these growths are many germs. (3) In picture number 3 one of the germs has entered a red-blood corpuscle of a person bitten by the mosquito. (4) In the corpuscle the germ divides into many parts, breaking the wall of the corpuscle. (5) The germs and their poisons enter the blood stream.

When animal germs get into the body, they multiply in different ways to produce more germs. Each germ may divide into two parts, as bacteria do; or each germ may divide into many smaller parts, each part being able to grow into a new germ.

Sometimes many-celled animals cause diseases. Do you ever eat raw or partly cooked meat? If you do, you have had an opportunity to take parasitic worms into your body. Occasionally meat contains young *tapeworms*. If the tapeworms are not killed by the heat of cooking, a young worm may fasten itself to the wall of the intestines. Then the tapeworm absorbs liquid food material that the body needs, and, in time, grows very long.

Trichina worms are occasionally found in large numbers in pork (Figure 312). If they are not killed by heat during cooking, hundreds or thousands of these microscopic worms get to the muscles of the body and bury themselves there. They cause a disease called *trichinosis*, which injures the body and sometimes causes death.

In warm regions where people go barefoot, *hookworms* burrow through the skin of the feet. Finally they reach the intestines and drain blood from its walls, making the person weak, so that he can take other diseases easily.

Some diseases, such as common colds, influenza, mumps, and measles, have puzzled scientists greatly. They act like germ diseases. They are easily spread from one person to another, and they make us sick in a similar manner. But the germs that cause these diseases have never been found. When discharges from the bodies of persons suffering with these diseases are filtered, no germs can be found in the filtered liquids. Yet we know that these discharges cause diseases in other people.

FIG. 312. A trichina worm in pork

What, then, really causes these diseases? We do not know. So the best we can do is to take proper care of our bodies and try not to expose ourselves to these diseases. Probably some day scientists will know their causes and find treatments for all of them, as they have for smallpox, diphtheria, typhoid fever, scarlet fever, and other diseases.

Self-Testing Exercise

Divide the names of the diseases below into four lists according to their causes: *Plant Germs*, *Animal Germs*, *Uncertain*, and *Many-Celled Animals*.

common colds	scarlet fever	tuberculosis
malaria	pneumonia	measles
influenza	sleeping-sickness	hookworm disease
mumps	typhoid fever	trichinosis

Problem 2:

HOW DO GERMS MAKE US SICK?

WHAT HAPPENS WHEN GERMS GET INTO OUR BODIES? How do you feel just before you have to go to bed with a disease—measles, for example? You feel tired, you cannot eat, your head aches, your eyes burn, and perhaps you have fever. What do germs do to your body to make you feel this way?

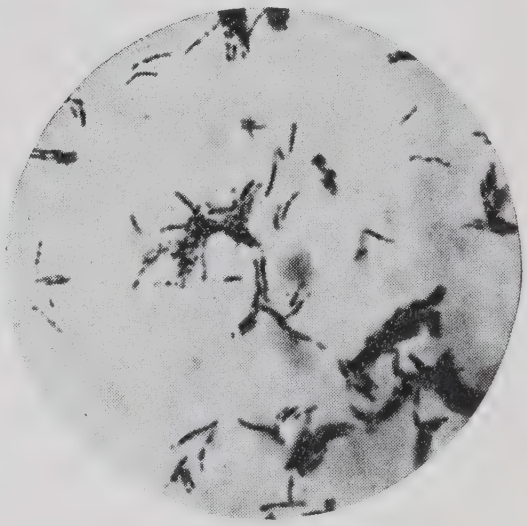


FIG. 313. Diphtheria germs, magnified thousands of times

Germs, like other living things, need food, moisture, and warmth in order to thrive. But unlike most living things, they need darkness instead of sunlight. When germs get inside the body, they find all of these conditions and begin to grow at once. And how fast they multiply! In about fifteen minutes a single bacterium divides, and there are two bacteria. In fifteen minutes more these two have divided, and there are four; in another fifteen minutes there are eight, and so on. In less than a day at this rate there would be more bacteria than there are people in the United States.

Fortunately for us, germs cannot continue to multiply at this rate of speed for very long. Lack of food and the poisons they produce help to hold them in check. Then, too, when the body is in good condition, it fights them, as you will learn later.

Once germs are in the body, they begin to seek the part of the body best suited to their growth. Tuberculosis and pneumonia germs grow best in the lungs. Dysentery

and typhoid germs grow best in the intestines. Malaria germs prefer red-blood cells. Some kinds of germs, however, seem to grow well in any part of the body.

When germs reach the part of the body where they can grow best, they immediately begin to do their damage. As you know, the body is made of millions of tiny cells. Germs must have food in order to live; so they get their food from the cells of the body. This destroys great numbers of cells. Of course, the body builds new cells to take the place of those destroyed by the germs. But this work of building the new cells puts an extra strain on the body, because the body must make new cells in addition to carrying on the rest of its work.

Have you ever seen a "boil" on someone's skin? How did it look? Usually the skin is red and "angry-looking," and the area around it is swollen. A boil is not a very pleasant thing to have because it is very painful. How did the germs cause a boil to happen?

As germs grow, they give off poisonous substances. Did you ever hear a doctor speak of *toxins?* Toxins are poisonous substances produced in our bodies by germs. The case of a boil is simple, because the poisoning is limited to a small area. The boil soon bursts and lets out masses of material known as *pus.* Pus is the whitish, watery-looking material that collects in boils and other sores. It contains masses of germs, dead body cells, and the white corpuscles of the blood that helped to destroy germs.

Other diseases may not be as simple as boils. Germs may make toxins that are spread to many parts of the body. For example, diphtheria germs growing in the throat give off a toxin that enters the blood and poisons the heart, nerves, and kidneys. Perhaps you have had your tonsils removed. Why was this necessary? Some kinds of

germs are able to live and grow in certain parts of the body, such as the tonsils, the teeth, and the *sinuses*. The sinuses are small pockets in the bones of the head. These germs do not make us sick immediately, but they furnish a constant supply of germs and poisons that finally cause serious diseases, such as rheumatism and heart trouble. One of the difficulties in curing these diseases is to find the source of *infection*, that is, the place where the germs are producing their poisons.

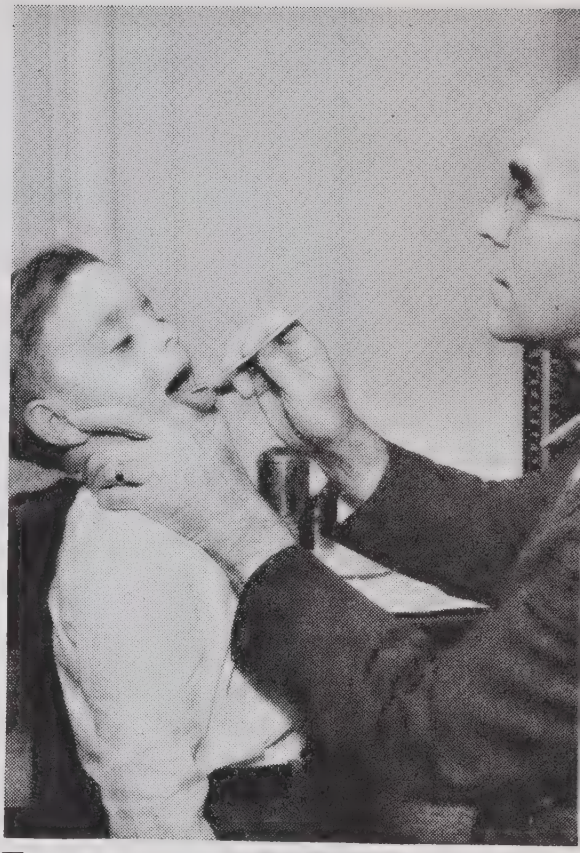


FIG. 314. The doctor is looking for signs of a disease. (Ewing Galloway, N. Y.)

HOW CAN DOCTORS TELL WHAT KIND OF DISEASE YOU HAVE? When a doctor examines a patient, he looks for signs, or *symptoms* (Figure 314). We say that he makes a *diagnosis*. Headache, a fever, chill, breaking out of the skin, pus, and many other symptoms give the doctor a clue as to what the disease may be. Doctors have watched the development of many cases of disease; therefore they can usually tell by the early signs what disease is making the patient ill.

Scarlet fever nearly always begins with the same effects. The person thinks he is developing a slight cold. His nose runs, his eyes burn, his throat is sore, he has a "strawberry-red" tongue, and a slight fever develops. Soon the fever increases, and a bright red *rash* appears upon the skin. These spots make the doctor fairly certain that the patient has scarlet fever. Other diseases have their own peculiar early signs.

Self-Testing Exercises

1. How are germs like other living plants and animals in the things they need to keep them alive and to make them grow? How are they unlike other living things in these ways?
2. How many bacteria could be produced from one bacterium in an hour? What keeps bacteria from reproducing at this rate for a long time?
3. What is a toxin? What effect does it have?
4. How do doctors diagnose a disease?

Problems to Solve

1. Describe how you felt when you were coming down with some disease, such as measles. What did the doctor do to discover what kind of disease you had?
2. Consult reference books to find what the symptoms of various kinds of diseases are, or ask your doctor what the symptoms are.

Problem 3:

HOW DO OUR BODIES FIGHT DISEASE?

How do our bodies keep out germs? Think of the countless number of germs we come into contact with almost all of the time! Why is it that most of us are able to go healthily and happily along, scarcely ever thinking of diseases at all? It is because our bodies protect us against the germs that would injure us.

When we burn or scrape bits of skin from our bodies, what is the first thing we do? We do the same thing that nature has done for our bodies. We cover the wound with some kind of substance to keep germs out. Your entire body is covered with a protective layer of skin that keeps germs from getting to the more delicate inside parts.

Most infectious diseases enter our bodies through its openings, such as the mouth, nose, and eyes. Even here the body has ways of protecting itself. The cilia that line

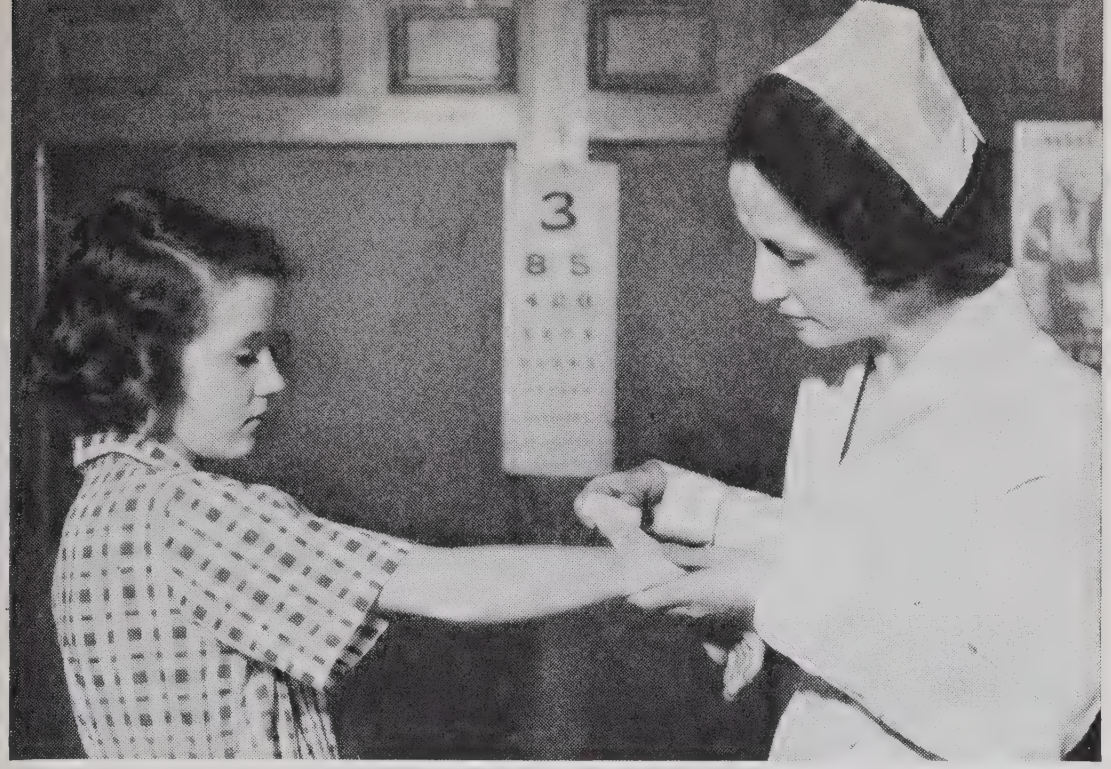


FIG. 315. Doctors and nurses are careful to bandage wounds in order to keep germs from getting into the wounds and into the delicate organs inside our bodies. (Ewing Galloway, N. Y.)

the air passages to the lungs sweep dust and germs back toward the outside (page 394). The sticky liquids given out by the cells catch germs, stick them together, and help us to get rid of them. Coughing and sneezing help to blow dust and liquids containing germs out of our air passages. Many germs that get into the stomach are killed by the juices in the stomach. Thus, you see, germs may have quite a hard time getting into our bodies.

Self-Testing Exercises

1. Give three ways in which germs are prevented from entering the body.

2. Suppose you stick a rusty nail in your foot. List the steps you would take in treating the wound. Opposite each step of the treatment tell why you would do it.

HOW DO WHITE CORPUSCLES FIGHT GERMS? Suppose germs do get into your body through the protective covering of the skin or through the mouth or nose. What happens in your body then? Whether the germs locate themselves in a break of the skin, in the throat, in the

lungs, or in any other part of the body, you still have something to help you fight them. As you learned in Unit 8, the blood contains many tiny, colorless cells known as white corpuscles. When germs get into the body and begin to grow, the white corpuscles travel to the place where the germs are. These corpuscles then attack the germs, kill them, and change them into substances harmless to the body.

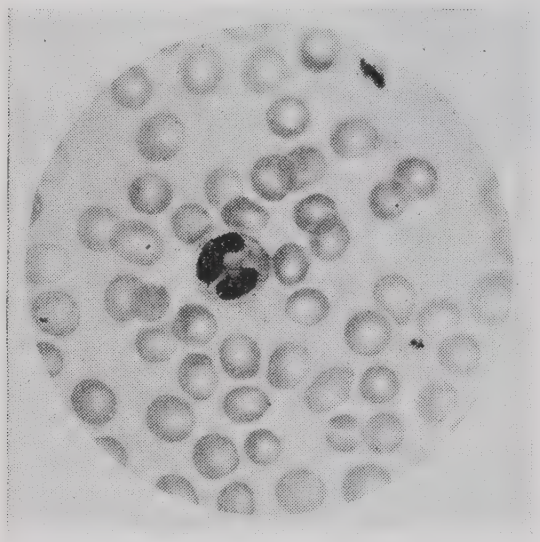


FIG. 316. Red-blood cells and one white corpuscle, which is plainly visible near the center.

If the body is in good condition, there will be plenty of white corpuscles free to attack germs. In this way the white corpuscles often keep us from having diseases. Up to a certain amount, the healthy body can also manufacture more white corpuscles as they are needed. This usually happens when there is some infection in the body. One of the tests used by physicians is the *blood count*. In this test the physician counts the number of red and white corpuscles in a certain amount of blood. If the number of white corpuscles is too high, the physician knows that there is infection somewhere in the body, because the body is manufacturing extra white corpuscles to fight the infection.

Doctors tell us a very startling fact that shows how the white corpuscles protect us. They say that there are very few adult people whose lungs do not have some *scar tissue* in them. This scar tissue is caused by tuberculosis germs that began their work and were stopped by the white corpuscles. Indeed, it seems that our bodies are

battle-grounds of a constant warfare between disease germs and the white corpuscles.

Self-Testing Exercises

1. How do the white corpuscles help the body?
2. Suppose you are not feeling well. Your doctor makes a blood test and tells you that you have more than the usual number of white corpuscles. What would this tell you?

WHAT GERM-FIGHTING CHEMICALS DOES THE BODY MAKE? In addition to its protection from germs by means of a skin covering, tiny hairs in the breathing tubes, and white corpuscles, your body has another way of fighting disease germs. Your body manufactures chemicals that help to keep you from having diseases.

Let us see what these chemicals do to germs. Some of the chemicals make it easier for the white corpuscles to attack the bacteria. Others cause bacteria to stick together in bunches, so that they cannot spread over the body. Some chemicals actually kill and dissolve bacteria. Other chemicals change the toxins produced by germs into harmless substances. These last kinds of chemicals are called *antitoxins* (*anti* means "against," and, as you know, *toxin* means "poison").

Most people who have not had scarlet fever take this disease when they get some of the germs in their bodies; yet it is seldom that a person has the disease a second time. Why is this true? Scientists have found that if you have scarlet fever, the chemicals produced to fight the scarlet-fever germs and toxin remain in your body during the rest of your life. Then you are said to be *immune* to that disease. Diphtheria, mumps, and measles are other diseases that usually leave your body immune after one attack. To what diseases are you immune?

FIG. 317. Many people take cod-liver or haliver oil, which contain large amounts of vitamins, to help keep their bodies in good condition, especially in winter, when it is harder to get plenty of sunshine, fresh air, and exercise. This test room, used by a manufacturer of fish oils, has 1000 cages of rats. The rats are given the oil regularly as a test to be sure that the oil has the proper vitamins in it.

Suppose that you develop fever. The fever is a sign that you have some kind of disease germ in your body and that your body is fighting to overcome the germs. You should recognize fever as a sign that your body is fighting disease germs, and you should help it by going to bed and keeping quiet. If you exercise and eat foods that are hard to digest, then your energy will be used up in building new cells and in digesting food; therefore your body may not be able to make germ-fighting chemicals rapidly enough to win the battle against disease.

Have you ever heard someone say that his body was in a "run-down" condition and that he needed to "build himself up" for fear he would take some disease? He meant that his body had become weakened in some way, and that he did not have the extra energy needed to fight germs if they got into his body. It is best for you to keep in good physical condition at all times, for you never know when you may be exposed to germs. Such diseases

as pneumonia, tuberculosis, and common colds seem to attack our bodies much more easily when we are in a "run-down" condition. You can help your body to fight these diseases by keeping yourself in good condition all of the time, instead of waiting until you are sick to take care of yourself.

Self-Testing Exercises

1. Explain why it is usually impossible for a person to have such a disease as scarlet fever more than once.
2. List some of the diseases to which people are immune after they have had them once. List some of the diseases that you can have any number of times.
3. Have you ever been exposed to a disease, such as a cold, but did not take it? Why did you not become ill?

Problem 4:

HOW CAN WE HELP OUR BODIES FIGHT DISEASE?

HOW CAN WE MAKE OUR BODIES PRODUCE GERM-FIGHTING CHEMICALS? Have you ever been vaccinated for smallpox? Was your arm sore afterwards, and were you sick from the vaccination? How did this treatment help keep you from having the disease? About 150 years ago smallpox was a most dreaded disease. There was no known cure for it, and it has been estimated that in Europe during the eighteenth century one person out of every fifty died of smallpox.

An English doctor, Edward Jenner, noticed that many farm girls who milked cows became ill with *cowpox*, a disease of cattle similar to smallpox. Some of the substance from cowpox sores got into the bodies of the girls through scratches upon their hands. The cowpox sores soon healed, and the girls seemed to be immune to smallpox. Jenner used this idea in protecting people against

smallpox. He made a small scratch on the skin and placed some of the substance from cowpox sores upon the scratches. This was the beginning of vaccination (Figure 303). According to reports, vaccination for smallpox has been so successful that in New York City, for example, not a single person has died of smallpox since 1932.

When you are vaccinated against smallpox, a substance called *vaccine* is put into your body by scratching your arm or your leg. The cells of your body then begin to manufacture chemicals, or *antibodies*, to fight the vaccine. These antibodies stay in your body and make you immune to smallpox. The antibodies caused by smallpox vaccination remain in the body for about seven years. When the body becomes immune by working against poisons and producing its own antibodies, as with smallpox, we say the body has *active immunity*.

HOW ARE DISEASE-FIGHTING CHEMICALS MADE OUTSIDE OUR BODIES? With some diseases, however, our bodies cannot produce their own disease-fighting chemicals fast enough. In these cases disease-fighting chemicals must be made outside our bodies and put into them. For example, if you should become sick with diphtheria, the doctor would put into your blood a liquid that contains antitoxin. Diphtheria antitoxin is secured from horses whose blood has made protective substances.

To get antitoxin, diphtheria germs are grown in cultures in the laboratory. There germs make toxin, or poison, as they grow. The live germs are filtered out of the toxin, and the toxin is put into the blood of a healthy horse. Every few days a larger dose of toxin is given the horse. The blood of the horse makes antitoxins to overcome the diphtheria toxins. Then, some of the horse's blood is taken, and the watery part is separated from it.

The watery part contains the antitoxin that is put into our blood to help us resist diphtheria. This method of protection against disease gives our bodies *passive immunity*. It is called passive immunity because our bodies do not produce the antitoxins.

If you take *toxin-antitoxin* treatment against diphtheria while you are still free from the disease, your body produces chemicals to fight diphtheria germs and their toxins. Thus the treatment gives your body active immunity. There is a test by which you can tell, even before you are exposed to diphtheria, whether you would be likely to take it. This is the *Schick Test*, discovered only a few years ago by Dr. Bela Schick of New York City. A very small amount of diphtheria toxin is put under the skin of your arm. If a little red spot appears several hours later, you will be likely to take diphtheria if you are exposed to it. If no red spot appears, you are not likely to "catch" the disease.

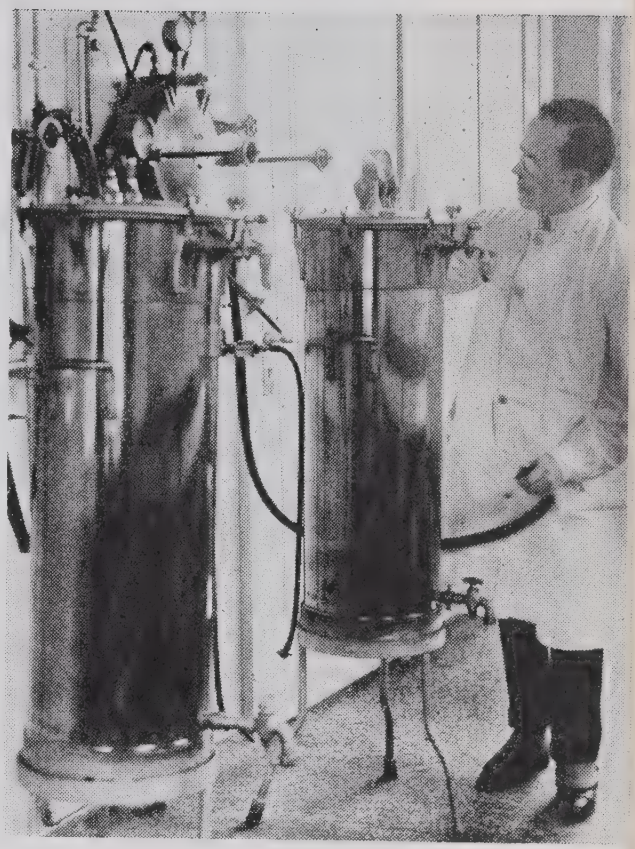


FIG. 318. Preparing serum for use in fighting diphtheria, typhoid fever, and other diseases.

When the Schick Test shows *positive* (a red spot appears), you are given the toxin-antitoxin treatment; small amounts of diphtheria toxin-antitoxin are put into your blood. If you wait until after signs of diphtheria appear, you are given only antitoxin to help your body fight the disease. And if you wait until the disease has fully developed, antitoxin is much less likely to help you.

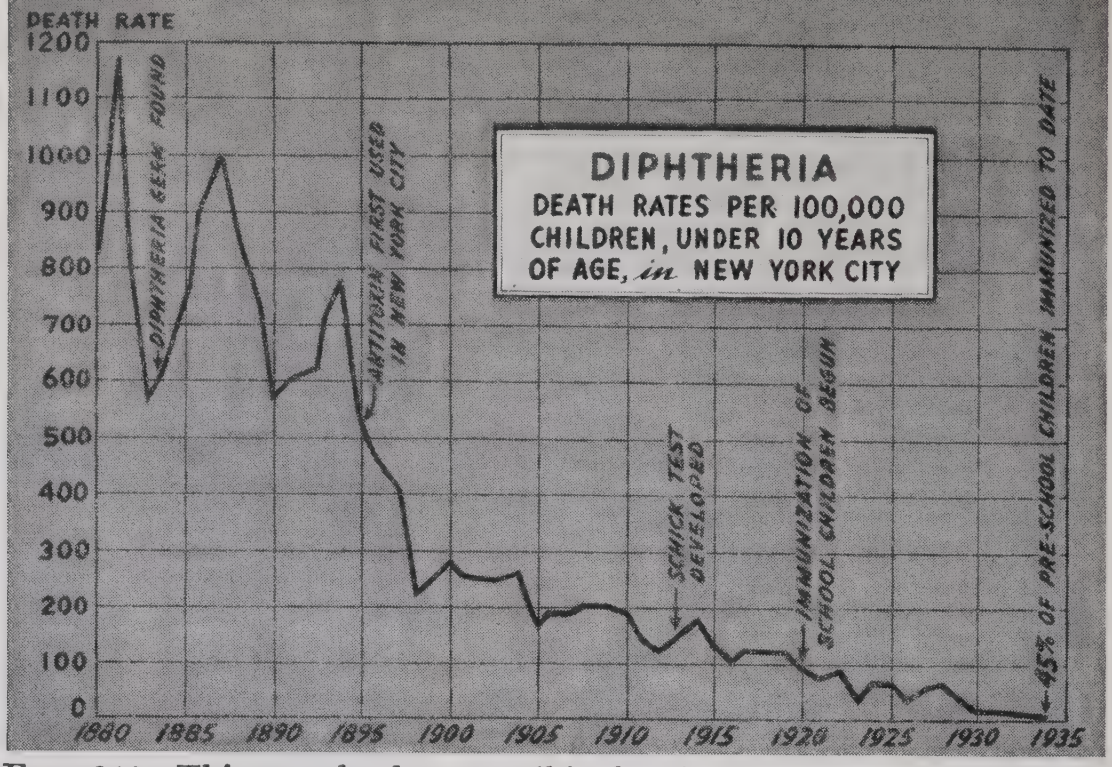


FIG. 319. This graph shows strikingly the decrease in diphtheria cases in New York City since 1895 as a result of the toxin-antitoxin treatment. In about 1882 there was an epidemic that killed twelve children out of every thousand. There were other terrible epidemics in 1887 and in 1894. Notice what happened to the death rate when the use of antitoxin was begun. About when was the diphtheria germ discovered?

You can also take a test to show whether you would be likely to take scarlet fever. This test was discovered by Dr. George Dick and his wife, Dr. Gladys Dick, of Chicago. Treatment consists of toxin and antitoxin that are prepared from a horse's blood. This treatment is very successful if it is given in time. The *tuberculin test*, given in a manner similar to the Schick and Dick tests, shows whether a person has tuberculosis.

In addition to immunization against smallpox, diphtheria, and scarlet fever, we can be made immune to lockjaw, typhoid fever, cholera, paratyphoid fever, Asiatic cholera, bubonic plague, yellow fever, and rabies (caused by the bite of a "mad" dog). The treatment varies for these different kinds of diseases. In some cases weakened or dead germs are put into the body to cause it to make antitoxins. In other cases weakened toxins or toxins mixed with antitoxins are used.

Self-Testing Exercises

1. Explain what happened in the blood of the farm girls (described in the problem) when they had the cowpox that kept them from having smallpox.

2. What do we mean when we say that the body is immune to a disease? To what diseases are you immune? Tell how you became immune in each case.

3. What do the Dick and the Schick tests show?

Problem 5:

HOW CAN WE HELP PREVENT THE SPREAD OF DISEASE GERMS?

How are germs spread? Have you ever had scarlet fever, diphtheria, or whooping-cough? Such diseases are called *infectious diseases*, because the germs that cause them are easily spread from one person to another. When infectious diseases spread rapidly and many people get sick, we have an *epidemic*. Sometimes epidemics kill a large per cent of the entire population. The terrible Black Death 600 years ago destroyed about one quarter of the people of Europe. At least 25,000,000 persons died. More recently we have had epidemics in the United States, such as yellow fever in 1878, influenza in 1918, and infantile paralysis in 1934, 1935, and 1936.

As scientists have learned more about the causes of disease, they have been able to work out ways of checking the spread of infectious diseases from one person to another. Suppose you pass a friend's house on the way to school and see a quarantine sign on the door (Figure 320). What does this mean? It means that someone in the family has a germ disease, and that the family must stay away from others until the danger is over. Our bodies are natural living places for many kinds of germs, but these germs cannot live outside of the body for any

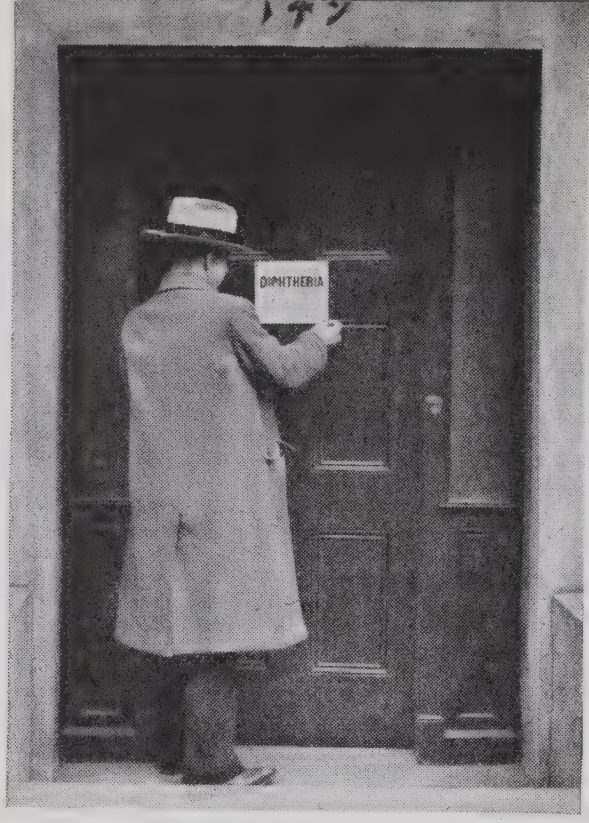


FIG. 320. What does this diphtheria quarantine sign tell all the persons who pass or come to this house? (Ewing Galloway, N. Y.)

length of time. So, in order to spread disease, germs must be passed to well persons directly from sick persons. They may also be passed from persons who carry the germs in their bodies, but are not sick. Such persons are called *carriers*.

Perhaps you have wondered why you were kept out of school when you had been exposed to a disease, even though you were not sick at the time. Most diseases have a definite number of days from the time the germs enter the body and begin to grow until the person shows signs of the disease. This period is called the *incubation period*, and it varies with different diseases. For diphtheria the incubation period is from 1 to 5 days; for whooping-cough, 8 days; for chicken-pox, 11 to 22 days; for measles, 8 to 15 days; and for mumps, 15 to 22 days. A person cannot be sure, therefore, that he has not caught a disease until the period of incubation is over.

Even after a person has recovered from a disease, he still may be a carrier. For this reason the period of quarantine is usually continued for awhile even after a person has recovered. For some diseases, such as diphtheria, the health officer usually makes a *culture* from a person's throat before the quarantine is lifted. The culture shows whether there are still disease germs in the person's body. This is done to be certain that the person is not a carrier.

Let us see how germs are passed from one person to another; then we will know better how to protect ourselves and others. When a person is ill, body discharges such as saliva, droplets from the nose and throat when sneezing, and discharges from intestines and from sores all contain germs. Certainly the best way to avoid "catching" a disease is to keep people who are sick away from others. And when we ourselves are sick, we should willingly stay at home.

But suppose someone is sick and does not know it? How can you protect yourself against such a person? The best way is to avoid handling articles that might have germs on them. Keep pencils and other objects out of your mouth. Do not eat foods after others have bitten from them. Use your handkerchief when you sneeze or cough. Do not drink from drinking cups that others use. Look about you and see what other ways you can suggest for protecting yourself and your classmates.

FIG. 321. By not covering his mouth, this sneezing boy not only has bad manners, but he may also spread disease among his playmates.

Disease germs may be spread in foods, such as milk, meat, fruit, and vegetables. Dirty milk bottles and cans, and dirty dairies where unclean people do the milking, may start typhoid, diphtheria, tuberculosis, and scarlet fever. Cows should be tested for tuberculosis. This disease is very common among cattle, and milk from a tubercular cow would be almost certain to

spread the disease. Visit a dairy when you have a chance and notice the many ways in which milk is kept clean.

Most dairymen, grocers, fruit-market operators, and other persons who sell food to the public are proud of the way in which they care for their products. Some methods of getting rid of germs and caring for products are *pasteurization*, *refrigeration*, *sterilization*, and *fumigation*. Pasteurization means killing germs in foods, chiefly milk, by heating the food to a temperature of 144 degrees Fahrenheit and keeping it at that temperature for about thirty minutes. This amount of heat is great enough to kill germs, but it does not destroy the value of the food. Refrigeration helps prevent the spread of germs by keeping the temperature too low for them to grow.

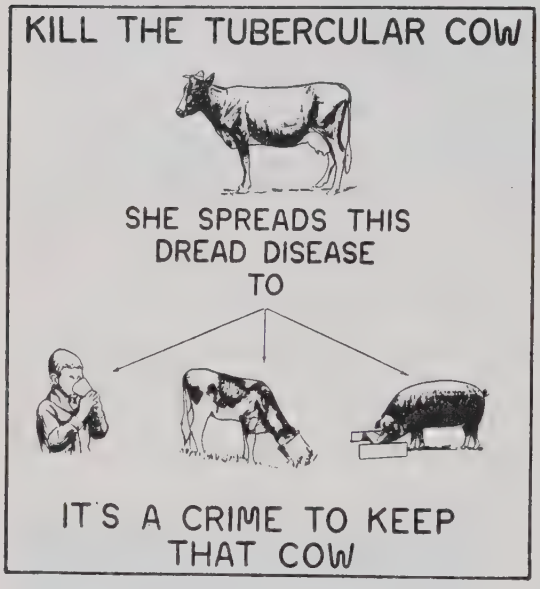


FIG. 322. This poster has been used in a nation-wide war on the tubercular cow.

Sterilization means killing germs on dishes, doctor's instruments, and other objects by heating these objects in boiling water or live steam or by dipping them in chemicals to kill the germs. Fumigation is a different process. When a person has been sick with certain contagious diseases, the room where he stayed should be freed from germs. This is done by heating some kind of germ-killing chemical until it turns into vapor. The vapor gets into all parts of the room. It gets into the cracks of the walls and on to the furniture and other objects and kills the germs.

Insects also carry diseases. Malaria is carried by mos-

quitoes. Ordinary house-flies carry typhoid germs, chiefly, but they may also carry tuberculosis and other germs. Fleas, lice, and bedbugs can all carry certain kinds of diseases from one person to another. The best ways of protection are to destroy the rubbish and filth where such insects lay their eggs, to screen our homes, and otherwise to keep these pests away from ourselves and our food.

FIG. 323. These colonies of disease germs grew on a gelatin culture after a fly had been allowed to walk over the gelatin.

In addition to the germs that live inside our bodies and are passed from person to person, there are germs that ordinarily live outside the body. When these germs get into the body through cuts, sores, or other breaks in the skin, sickness and death often follow.

Notice what precautions a doctor takes with his instruments. Suppose you have a boil that needs lancing. The doctor boils his tweezers, needles, and other instruments in order to sterilize them, or to kill the germs on them. He washes his hands with some kind of germicidal, or germ-killing, soap before he goes to work, and sometimes he even wears sterilized rubber gloves. He bathes the boil with a chemical to kill the germs that are on the skin around the boil. After he has drained the pus from the boil, he puts some *antiseptic* into the wound. An antiseptic is a chemical that prevents the growth of germs. Then he makes a neat bandage of sterilized gauze to keep out

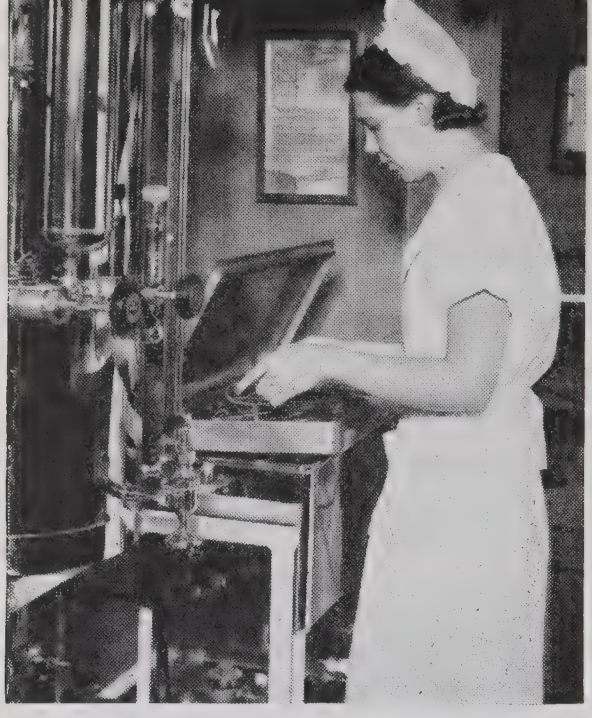


FIG. 324. Sterilizing surgical instruments in a large hospital in New York City (Ewing Galloway, N. Y.)

any new germs that might get into the wound.

If doctors are so careful to avoid infections when it is necessary to break open the skin, surely we can paint cuts and scratches with iodine, mercurochrome, or some other good antiseptic that the doctor recommends, and put clean bandages over them.

Self-Testing Exercises

1. Is this statement true? A person sick with a contagious disease is a carrier of that disease, but a carrier of a contagious disease does not have to be a sick person. Explain.
2. Make a list of the ways in which disease germs may be passed from one person to another. For each item in your list tell how this transfer of germs can be avoided.
3. List as many ways as you can to keep germs from getting from sick people to well people.
4. Tell how to keep germs from getting into your body through a broken place in the skin.

Problems to Solve

1. With the aid of your class, make a list of all the diseases that your classmates have had during the year. For which of these should people be quarantined?
2. Make a list of ways in which disease epidemics could be started in your community. Opposite each item in this list tell what your community does to prevent epidemics.
3. In reference books read about plagues that have swept over parts of the world at various times in history.

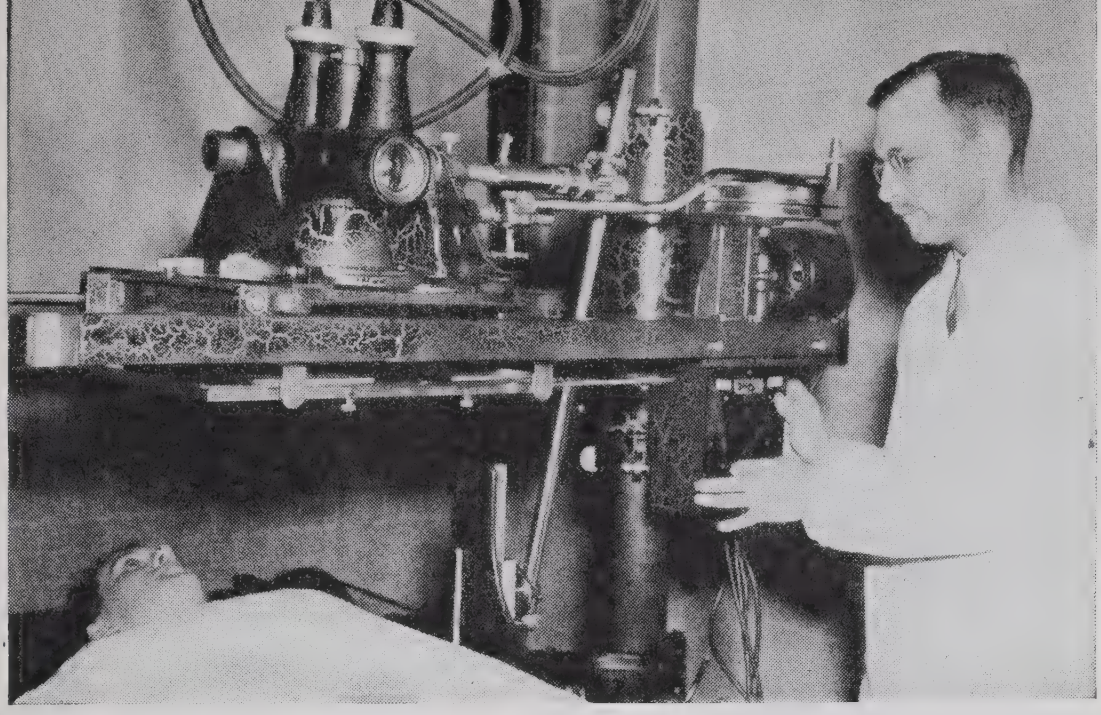


FIG. 325. One of the greatest aids to preventive medicine is the X-ray machine. The rays of this machine can go through the human body and make a photographic plate of the organs, the flesh, and the bones. This photograph enables the doctor to discover some diseases in their earliest stages, when they can be cured more easily.

WHAT IS PREVENTIVE MEDICINE? Does it seem strange that in some countries people used to pay doctors to keep them well? People did not wait until they were sick to send for a doctor. They paid doctors to tell them how to keep from having diseases. People are coming to realize that this was a good practice; so today we are learning to keep diseases from getting started, instead of waiting until we are sick and then running the risk of not being able to be cured. Such practice is called *preventive medicine.*

How does preventive medicine work? As you have learned, the body can resist diseases better when it is in good condition. You can go to a reliable doctor at least once a year to find out whether your body is working properly. If you find that you have bad teeth, bad tonsils, or other defects, you can have these treated before they injure some vital organ of your body, such as the heart or lungs. You can get plenty of sleep, eat the right kind of foods, play in the fresh air and sunshine as much as possible, and keep your body clean. When you do these things,

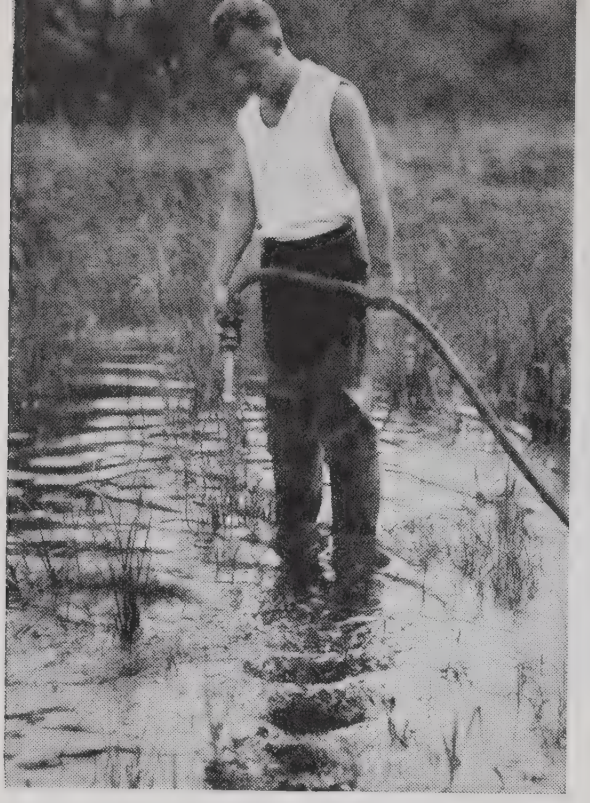


FIG. 326. In New York City the Department of Health carries on the fight against mosquitoes from spring until frost comes by pouring oil on the water where they breed. The oil smothers the larvae, that hatch from eggs laid in stagnant water. (Ewing Galloway, N. Y.)

you are at least giving your body a chance to do its work well. Of course, if you become ill with a disease, you should call a good doctor as soon as possible and do as he says. A good doctor follows the best practices of the medical profession and does not advertise quick cures or depend upon patent medicines. He suits the treatment of each disease to the needs of the person he is treating.

What are some other good health habits that you can have? You can think straight about your health problems instead of worrying about yourself. You can be willing to change your opinions about health matters as new discoveries are made. You can select wisely the doctors to whom you go so that you can have confidence in them. Having confidence that you will win when you and the doctors are following the best practices will help you and your community in the fight against disease.

What has just been said about preventive medicine helps each of us as individuals, but that is not enough. We must be willing to work with others in securing healthful conditions for our community. If our neighbor is careful in his health habits, while we are careless and expose him to diseases that we have taken, we undo all the good that he has done.

We can learn to work together to rid our homes first, and then our communities, of insect pests, such as flies and mosquitoes. We can do this by draining wet places, cleaning up filth that provides breeding places for such insects, and screening our buildings. We must be willing to have ourselves vaccinated against infectious diseases, and we must be honest in obeying quarantine rules when we have an infectious disease. We can insist that our food and water supplies be protected from germs and from the insects that carry germs.

Self-Testing Exercises

1. What practices of preventive medicine do you follow regularly?

2. List the practices of preventive medicine that you should, but do not, follow.

3. Make a list of ways in which people of your community work together to make it a healthful place in which to live. Suggest other ways that would help.

LOOKING BACK AT UNIT 8

1. Answer the following questions, using a paragraph of at least one-third of a page for each question. Work with your book closed.

a) What kinds of plants and animals cause disease?
b) How do germs make us sick?
c) How does your body protect itself against disease germs?
d) How can we help our bodies fight disease?
e) How can we help to prevent the spread of disease germs?

2. Show that you know the meaning of each of these words.

cilia	*carrier*	*active immunity*	*antiseptic*
toxin	*antitoxin*	*passive immunity*	*fumigation*
vaccine	*vaccination*	*incubation period*	*pasteurization*
epidemic	*symptom*	*infectious disease*	*sterilization*
coccus	*bacillus*	*organic disease*	*spirillum*

ADDITIONAL EXERCISES

1. Find the difference between *certified* and *pasteurized* milk. Which is more expensive? Why?

2. Learn how milk is pasteurized. Pasteurize a sample of milk and compare it with a sample of raw milk. Which spoils the quicker?

3. To find what a *germicide* does, ask your teacher to put three drops of mercuric-chloride solution into a test-tube of milk. Label the test-tube "poison." Smell the milk in the tube after several days. Has it curdled or soured? Keep a second test-tube of milk with the first one, but put no mercuric chloride into it. How does it act? Explain the difference. (NOTE: **Do not attempt this exercise except under the careful direction of your teacher.)**

4. Does weather have any effect upon disease? Keep a record of the number of days missed from school by the members of your class on account of sickness. Make this into a graph. During what months were there the most absences? What kind of weather generally prevails in your locality during these months?

5. Examine a fly's foot under the low-powered lens of a microscope. Does this help to explain why the fly is a carrier of disease germs?

6. Find how the following men helped in the fight against disease germs: Edward Jenner, Robert Koch, Joseph Lister, Louis Pasteur, and Walter Reed.

7. In reference books find graphs for other diseases, like the one for diphtheria on page 426. Or get the figures from health reports for your county, city, or state and make graphs for your class. What do they show?

FIG. 327. This baby gorilla was born in a zoo. Every day he is weighed to be sure that he is growing as a young gorilla should grow. If you had charge of the animals in a zoo, you would have to know much about how animals are born and how they grow to full size. But zoo-keepers are not the only ones who have to know how life continues on the earth. Farmers, gardeners, and greenhouse keepers must understand how plants and animals are *reproduced*. In this unit you will learn the important things that scientists have learned about the reproduction and growth of living things.

UNIT TEN

UNIT 10

HOW DOES LIFE CONTINUE ON THE EARTH?

INTRODUCTORY EXERCISES

*1. What is a cell?

*2. What are the parts of a cell?

3. Name as many different ways of producing new plants as you can.

4. (*a*) Make a list of animals that lay eggs. (*b*) Do baby rabbits come from eggs? Explain.

5. Compare the parts of a bean seed with the parts of a hen's egg. What parts are alike? What parts are different?

6. Find how much you weighed when you were born. How much do you weigh now? What is your average gain in weight a year?

7. Make a list of changes that have occurred in you from the time you were a baby until now. You already know one change. Add others to the list. *Example:* (1) I have gained in weight from ..... pounds to ..... pounds.

8. Make a list of changes in some plant that you have watched grow. *Example:* (1) Seeds develop roots and stems. Add as many other changes as you can.

*9. How do green plants make food?

*10. What do root-hairs do for a plant?

*11. How do food-making materials and food travel from one part of a plant to other parts?

12. Many animals increase in size at about the same rate during different seasons of the year. Is the same true of plants? Tell why you believe your answer is correct.

FIG. 328. All living things are made from other living things. The mother turtle laid soft-shelled eggs in a hole she dug in the soil near a stream or pond. Inside the eggs the little turtles began to grow. In a few weeks they hatched.

LOOKING AHEAD TO UNIT 10

DID YOU EVER watch a pair of robins build a nest? It was an interesting sight, wasn't it? When the nest was completed, the mother laid eggs and kept them warm with her body. In about two weeks young birds were in the nest. The little birds had no feathers, and they scarcely looked like birds. But they grew fast. Soon they learned to fly and search for their own food. By that time they were as large as their parents. It hardly seemed possible that so much could have happened to them in such a short time. There are many wonderful stories of science and of what scientists have learned. But the most interesting and wonderful of all is the story of how plants and animals start their lives and how they grow.

People in the past have had curious ideas as to how living things come into being. Only 250 years ago most people believed the theory of *spontaneous generation*. This is the theory that living things grow out of non-living matter. Some examples will make it clear to you. You

have heard how ancient people believed that frogs develop from mud in the bottom of ponds. Ancient Greeks and Romans believed that bees develop from decaying horse flesh and that scorpions come from decaying crab meat. More recent stories tell us that horsehairs put into water develop into long, hair-like worms. There are still people who believe that mosquitoes just grow from stagnant water in ponds.

Over 200 years ago an Italian scientist, Francesco Redi, doubted the theory of spontaneous generation. So he worked out an experiment to help him find the truth. At that time one of the common ideas was that flies develop from decaying flesh. People thought this because they so often saw fly *maggots* on decaying meat. Redi put some meat into a clean jar and covered the mouth of the jar with gauze to keep the flies out. The flies were attracted to the meat but could not get to it. So they laid their eggs on the gauze. The result was that maggots hatched on the gauze, but none came from the meat. This showed that maggots develop from eggs laid by flies, and not from meat.

FIG. 329. We enjoy flowers for their beauty, but they are so important that many plants could not go on living without them. Do you know why?

Every year countless new plants and animals appear on the earth. So far as we know now, all these new living things come from other living things; that is, all living things come from a parent or from parents. The process in which new living things are created is called *reproduction*. One of your problems

in this unit is to discover how new plants and animals are produced.

Every living thing sooner or later dies. Some live for hundreds of years, while others live but a few minutes or hours. Without reproduction, therefore, living things would soon disappear from the earth. But reproduction is not the whole story. Living things must be able to grow; that is, they must be able to increase in size. Many changes must take place in the individual plant or animal while it is growing into an organism like its parent or parents. An egg, a seed, and a spore each has in it the beginning of a new individual. But this new individual is not a completed living thing until growth takes place.

FIG. 330. About twelve years ago you looked like this baby. What happened in your body to make you grow up to your present size?

We are so used to seeing things grow that we do not pay much attention to what is happening to them. We know that if all goes well, a tiny pup will some day be a grown dog, and a morning-glory seed will grow into a big vine. If we really stop to think how these living things change as they grow up, it all seems like magic. But you know from your study of science that things do not happen by magic. Scientists know what happens when living things grow. You, too, will know when you have studied this unit.

Perhaps you think that it is not important to learn how things grow—that if we leave them alone, they will "just

grow anyway." To a certain extent this is true. But if farmers can make their animals and plants grow faster and larger, they can make more money. Therefore they want to know what the scientist has discovered about growth. Doctors and nurses think it is important to know about growth. Then they can help people keep well and help boys and girls grow into healthy men and women. Your mother thinks so, too. She often asks, "Have you drunk your milk? Have you eaten your vegetables?" She does this because she wants you to eat food that will help you to grow.

Problem 1:

WHAT ARE SOME OF THE WAYS IN WHICH LIVING THINGS REPRODUCE?

BEFORE YOU study this problem, you will need to recall some of the things you learned in science last year. You learned that the bodies of all living things are made of cells. The bodies of simple things, an amoeba, for example, are made of only one cell. The bodies of more complex plants and animals, like trees and yourself, are made of millions of cells.

You will recall, too, that the living material in each cell is protoplasm. In the protoplasm is a denser part, called the nucleus. The nucleus controls the growth and the other activities of the cell. Without a nucleus, a cell cannot live long. Neither can it produce other cells. Since you know about cells, you can understand what happens when the cells of living things produce new living things.

WHAT IS THE SIMPLEST WAY IN WHICH PLANTS AND ANIMALS REPRODUCE? Look at a prepared microscope slide of a one-celled animal dividing, or study Figure 331. One of the simplest ways in which one-celled plants and animals reproduce is by dividing. When one of these

tiny living things begins to divide, its nucleus separates into two parts. Then the protoplasm separates into two parts, with one nucleus in each part, and there are two complete organisms instead of one.

Of course, the two individuals are only half as large as the original animal or plant was. So they grow until they are about as large as their kind gets to be. Then each one divides again, and there are four individuals. This kind of reproduction is called *fission*.

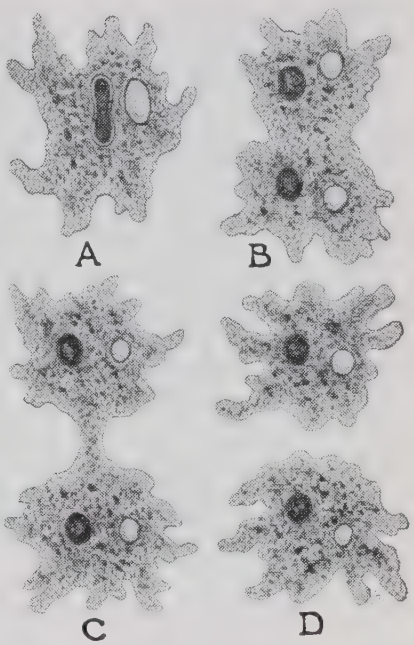


FIG. 331. How the one-celled amoeba is "born." From the single amoeba (A) have come two new amoebas (D).

EXPERIMENT 51. *How Do the Simplest Plants Reproduce?* Scrape some of the green, powdery material from the bark of a tree. It usually grows on the north side of the trunk. Put the material on a glass slide in a drop of water and examine it with a microscope. Can you find any single cells? Do you find any of the cells stuck together in groups of two or more? Make a sketch of some of these cells. How do you think these groups were formed?

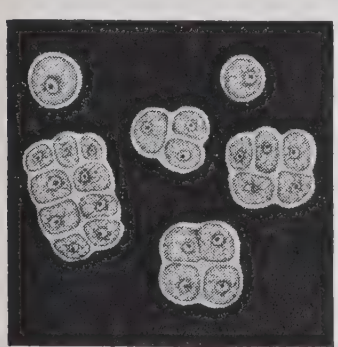


FIG. 332. Pleurococcus plants, as they look when they are highly magnified

The material you saw through the microscope was a number of very simple plants known as Pleurococcus (Figure 332). Each cell was a whole plant. Sometimes, after a plant has divided, the new plants stick together in a group, or *colony*. Pleurococcus is a plant that reproduces by fission, much like the amoeba. Many other microscopic plants reproduce in this man-

ner. For example, bacteria and other germs, which you studied in Unit 9, reproduce by fission when they get into a person's body. No one knows exactly what makes these simple plants and animals suddenly begin to divide and produce new organisms.

But only the simplest kinds of plants and animals reproduce by fission. Higher animals, such as earthworms, reptiles, birds, and mammals, and higher plants, such as beans and grass, reproduce in more complicated ways. You will learn about some of these later in this unit.

Self-Testing Exercises

1. What is protoplasm?
2. What is a nucleus?
3. Use a piece of modeling clay to represent a one-celled plant or animal. Show how the plant or animal reproduces.
4. How many amoebas will be produced from a single amoeba after ten divisions have taken place?

HOW DO SPORES HELP PLANTS REPRODUCE? Did you ever squeeze a dried puffball, or Devil's snuff box, as it is sometimes called? If you have, you saw powdery, dust-like material come from the puffball. Each little piece of dust was really a *spore*, and each of the spores could produce a new plant. Spores are really small cells that can start new plants. Each spore usually has a thick coat and contains some stored food. But spores are not at all like seeds, as you will learn later in the unit.

Many other kinds of plants reproduce by means of spores. Mushrooms and bread mold are two examples. Experiment 52 will show you how bread mold reproduces.

EXPERIMENT 52. *How Does the Bread Mold Reproduce?* (*a*) Moisten a piece of bread and leave it exposed to the air for an hour. Then lay the bread on a wet blotter in a dish. Cover the dish and put it in a warm place. Watch the bread

for several days. Be sure to keep the blotter wet. What happens to the bread? Examine it every day with a hand-lens. Note any tiny dark balls (*spore cases*) that form on the white, hair-like threads of the mold.

b) Dust some of the dark bodies on to a clean piece of fresh, moist bread. Put the bread on a wet blotter and care for it as you did before. Watch it for several days. What happens?

c) Dust some of the dark bodies on to a piece of old, dry bread. Put the bread in a dish, cover it, and keep it dry. Do the spores grow? What condition is necessary for spores to grow?

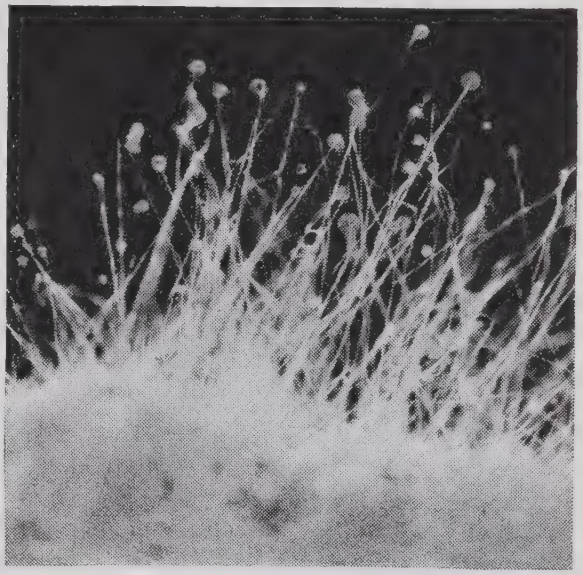


FIG. 333. How bread mold looks under a low-power microscope

Soon after you started the experiment, you probably saw a hairy mass of thread-like material form on the bread. This material, the *mycelium*, was the body of the bread mold. When you examined it with a hand-lens, it probably looked like threads with many branches. Part of the mycelium grew into the bread to get food. Part of it spread out over the top of the bread. However, as you watched the mold, it did not divide to form a new mold. Something much more interesting happened. Tiny white balls appeared on the ends of some of the branches (Figure 333). About a day later, you found that these balls turned black, as shown in Figure 334.

If you could have examined these balls under a high-power microscope while this change was going on, you would have seen that the protoplasm in the ball divided into hundreds of small bits of protoplasm. Each of these

bits of protoplasm was surrounded by a cell wall and contained a nucleus. Each one is a spore. Soon the spore case breaks open, and the tiny spores are scattered through the air. Each spore can grow into a new plant. You can see that by making spores each plant may reproduce thousands of other individuals like itself. Mosses and ferns are other kinds of plants that reproduce themselves by means of spores (Figure 335).

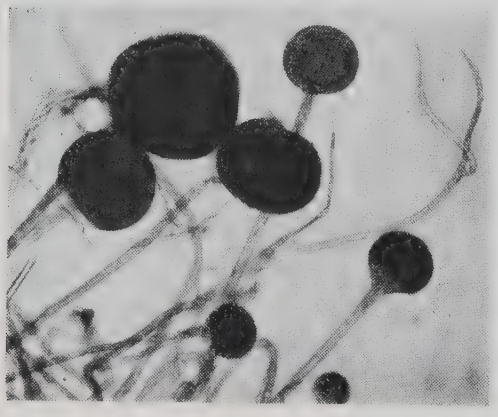


FIG. 334. Spore cases of bread mold under the microscope

Perhaps you have been wondering, "Why should I learn how these tiny living things reproduce?" We need to know how these simpler plants and animals reproduce so that we can keep them from growing when we do not want them, as you learned in Unit 9 and will also learn in Unit 11. Also, some of these simpler organisms are helpful, and we want to make them grow when we need them. Furthermore, if you learn how these simple living things reproduce, you can better understand the more complicated methods of reproduction.

You have already learned several things about reproduction: (1) Each kind of living thing has a method of reproducing itself. (2) The methods by which living things reproduce vary. (3) Some simple plants and animals merely divide to produce two individuals. (4) Some simple living things reproduce by means of spores. (5) In both of these methods of reproduction—fission and reproduction by spores—there is a separation of protoplasm in the parent organism, and each bit of separated protoplasm can grow into a new individual.

Self-Testing Exercises

1. What are spores? Give the answer in your own words.
2. Describe the appearance of mycelium and spore cases of bread mold. What does each part do for the plant?

Problems to Solve

1. Use some good reference book and make a list of spore-bearing plants that are not mentioned in this textbook.
2. Examine the under side of the leafy parts of ferns to locate any spore cases that may be there.
3. How does reproduction by spores differ from reproduction by simple fission? How are the two methods alike?
4. How can you keep bread so that bread mold will not start to grow on it?

FIG. 335. The lighter spots on the fern leaves are clusters of spore cases. They fall to the ground to make new fern plants.

HOW DO PLANTS REPRODUCE FROM PARTS OF THEIR BODIES? This part of the unit probably is not new to you, for you have often seen people grow new plants from parts of plants. Did you ever see a pussy-willow branch kept in water in the early spring? If it was kept there long enough, roots began to develop on the end of the branch that was under water. Many people plant these rooted branches out-of-doors in moist places, and they continue growing until they are mature trees.

EXPERIMENT 53. *How Can New Plants Be Reproduced from Parts of Plants?* If you do this experiment carefully, you can see new plants grow from parts of old plants.

a) Secure some pussy-willow branches. Keep them in water until they have rooted, as suggested above.

b) Put a long, slender sweet potato in a wide-mouthed bottle of water. The bulge in the potato will make it stick in the bottle so that one end will be in the water and the other end in the air. Watch to see what happens.

c) Cut several pieces of geranium stalk about four inches long. Remove all of the leaves except two or three at the top. Bury the stems in wet sand, but let the leaves and about an inch of each stem be above the sand. Keep the sand moist and watch what happens (Figure 336).

FIG. 336

d) Break several begonia leaves from a healthy plant. Bury about half of each leaf containing the broken end in wet sand. Watch to see what happens. If you can get a leaf of Bryophyllum from a florist, lay the whole leaf in a shallow dish of water or on moist sand. Keep it there for several weeks, watching what happens.

e) Cut an Irish potato into large pieces. Be sure that each piece contains an "eye," or bud. Plant the pieces in moist soil.

f) Secure some onions or other kinds of bulbs that have produced new bulbs. You can tell when this happens because the plants will be growing together in bunches. The original bulb has already produced the cluster of small bulbs that surrounds it. Examine these carefully.

Experiments like the ones you have done show more clearly than anyone could tell you how parts of plants grow into complete new plants. In each case one part of the plant, such as the root, leaf, or stem, was able to grow the parts of the plant that were missing. Scientists have a special name for this process of reproduction. They call it *regeneration.*

Strangely enough, some animals can reproduce by regeneration. A starfish, for example, has five arms. Oyster

fishermen used to cut the starfish to pieces when they caught them, because starfish eat oysters. However, much to the fishermen's surprise, the number of starfish increased, no matter how many were cut up. This puzzling situation was explained when the fishermen discovered that each arm of the starfish could regenerate the missing parts. Each arm thus produced a new starfish.

FIG. 337. Rhizome of a plant called "solomon's seal"

The fact that plants can reproduce from their parts is not always helpful. Sometimes people chop or plow undesirable grasses from their fields or lawns, only to find that the grasses spread all over the land. Certain kinds of grasses have underground stems known as *rhizomes* (Figure 337). When the field is cultivated, these stems are broken up into many parts and scattered. Each part grows into a new plant, and the field becomes grassier or more covered with weeds than ever.

In Experiment 53 you saw the sweet potato in water put out roots and probably leaves. It began to grow into a complete plant. This kind of potato is really only a root that contains much stored food. Farmers and gardeners plant sweet potatoes in the soil and get many new plants from each one. Then the new plants are broken off the potato and are planted in the fields where they are to grow and produce more potatoes.

Many kinds of flowers, such as geraniums, are started by planting parts of the vines or stems. You understand how this works from watching the cuttings of the ger-

aniums you planted in the experiment. In preparing a cutting you must be sure to get a piece of the stem with some *nodes* on it (places where the leaves and buds grow). Some of the leaves have to be left on the top end of the cutting to make it grow. Many nurseries sell cuttings of certain plants instead of selling the seeds of these plants.

FIG. 338. Roots and stems have sprouted from the "eyes," or buds, of this potato.

White, or Irish, potatoes, which are short, fleshy, underground stems, contain much stored food. On the surface of these potatoes are "eyes," or buds. Each of these buds can start a new plant. As in the experiment, the potatoes are cut into pieces, each containing a new bud. When a piece of the potato is put into the ground, a new plant begins to grow from a bud, while the piece of potato provides food until the new plant develops roots and leaves by which it can manufacture its own food.

Strawberries and other plants grow runners, or *stolons*, that lie along the top of the ground. These stolons have nodes, just as ordinary stems do. Where the nodes of these stolons touch the ground, new roots, stems, and leaves develop, and thus a new strawberry plant begins to grow. Have you ever heard the old saying that a field of strawberries will "keep themselves planted"? Now you know how the strawberry plants "plant themselves."

FIG. 339. You can see the stolon extending like a string from plant to plant. At one node only roots have grown. Later, leaves will grow up at that place, and a new plant will have developed.

One of the strangest ways of reproduction is found in a tropical plant known as Bryophyllum. When a leaf falls from this plant and lies on the moist ground, new plants grow from buds that form in notches in the edges of the leaves. In Experiment 53 you probably saw a cut begonia leaf do the same thing. A new plant began to grow from a part of the leaf.

The methods of reproduction that you have studied so far—simple fission, spore formation, and regeneration of missing parts—are all alike in one way. You can see that in each case a new organism or new organisms are produced from some part of an old organism. If conditions are right, the part of the old organism grows into a new organism, and the number of living things is increased.

Self-Testing Exercises

1. What happens when reproduction takes place by the process of regeneration?

2. How is reproduction by regeneration like reproduction by fission or by spores? How is it different?

3. What plants that are familiar to you reproduce by means of regeneration?

4. Name a plant that can do each of the following things:
a) Grow new stems and leaves from a root.
b) Grow new stems, roots, and leaves from a leaf.
c) Grow new leaves and roots from a stem.

5. What is the difference between *rhizomes* and *stolons?*

Problems to Solve

1. How is reproduction by regeneration useful to man? How is it harmful to man?

2. Why must cuttings have nodes to start growing?

3. Make a list of vegetables in your locality that can reproduce by means of regeneration. Opposite the name of each plant, write the name of the part that is used in the process, thus, rhizome, stolon, etc.

HOW DO PLANTS MAKE SEEDS? Some people think that the main purpose of flowers is to make our homes and gardens beautiful. But flowers have a much more important use than this. They are the parts of the plant that produce seeds. Each seed contains a tiny plant that can grow into a new plant. Let us see how flowers produce seeds with new plants inside them.

EXPERIMENT 54. *How Do Flowers Produce Seeds?* Get a large flower, such as a lily or a primrose, and take it apart. Lay each different kind of part by itself, so that you can label the parts and learn their use. If the flower is a primrose, the green outer parts will be the *sepals.*

Next remove the *petals.* Then remove the *stamens.* Look at Figure 340 for help in locating these parts. What is left will be the *pistil,* growing on a part of the stem called the *receptacle,* or holder. Put the pistil in a separate place.

If you found all the parts of the flower, you are now ready to go on with your study. The sepals and petals,

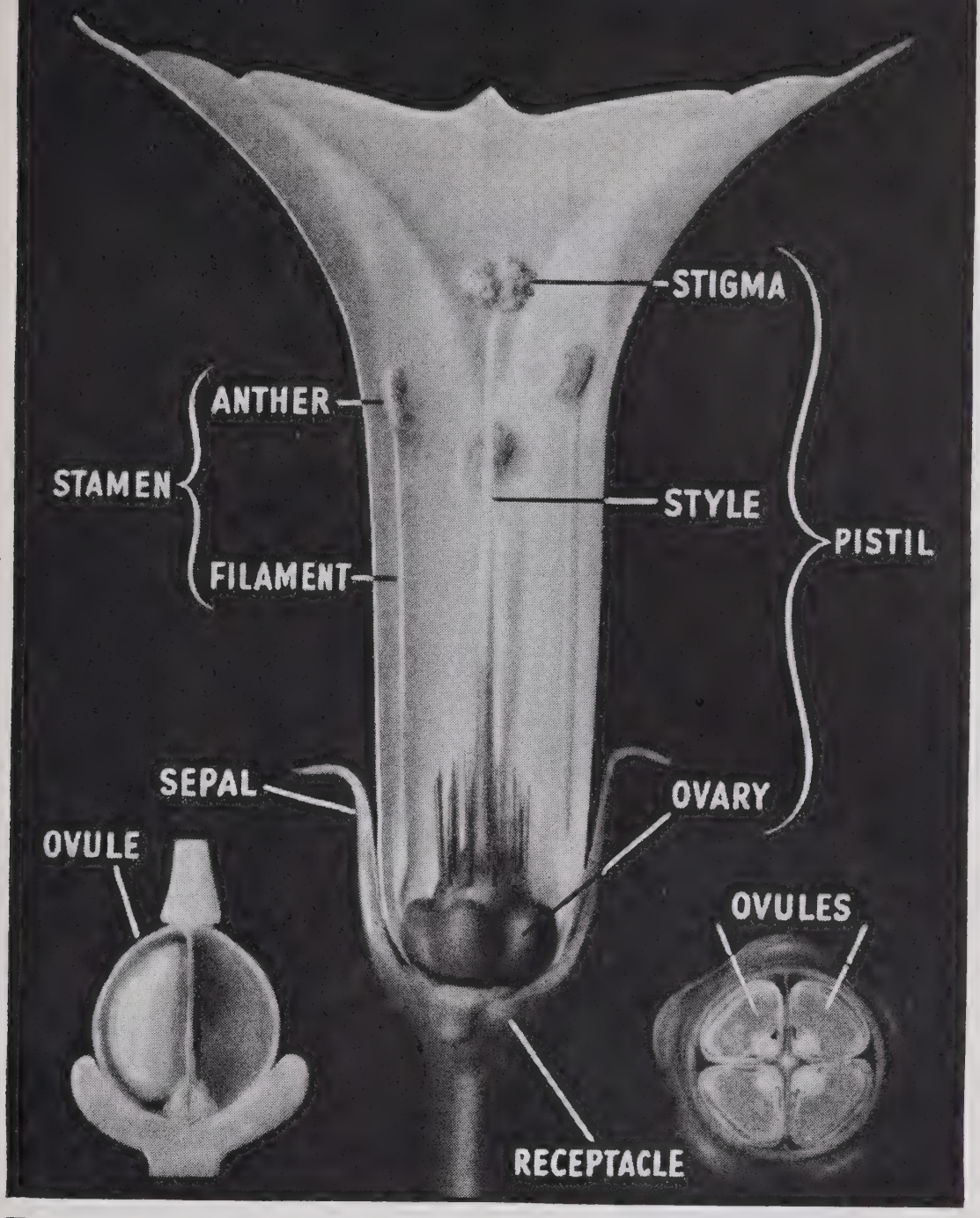


FIG. 340. This is a picture of an accurate wax model of the parts of a morning-glory flower. Two different views of the ovary, or seed container, are shown. At the right it is shown cut in two crosswise.

which are the showy parts of the flower, protect the delicate parts inside their flower. Some flowers do not even have sepals or petals. They can make seeds just as well without them; so we will not consider these parts further here. But the next parts you removed from the flower, the stamens and the pistil, were very important. Flowers cannot make seeds unless they have stamens and pistils.

The stamens are the male parts of the flower. They consist of little knobs (*anthers*) with yellow dust-like particles in them. The anthers are supported by slender stems called *filaments*. Examine an anther with a hand-lens. The yellow, dust-like particles are *pollen grains*. These pollen grains were formed by the division of cells in the anther. Sprinkle some pollen grains on a sheet of dark paper and examine them with a magnifier, or put them on a piece of glass and use a microscope. Examine the grains of other flowers (Figure 341).

The pistil is the female part of the plant. When a flower is mature, pollen grains are scattered from the anthers into the air. Some of these grains fall on the sticky tip of the pistil. This tip is known as the *stigma*. When a pollen grain falls on a stigma, the grain absorbs moisture, swells, and breaks its outer covering. Then a tube, known as the *pollen tube*, grows out of the pollen grain and down through the *style*. The style is the part of the pistil between the stigma and the *ovary*, or the seed container (Figure 340).

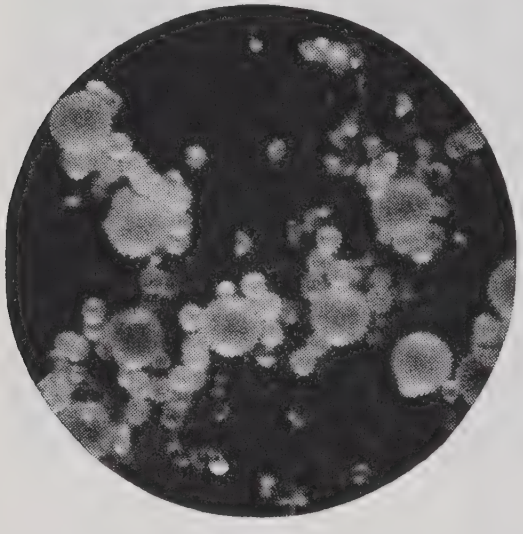


Fig. 341. Highly magnified pollen grains. The large ones are from the marsh-mallow. The smaller ones are from the dahlia.

While the pollen tube is growing, something else is happening inside it. A male, or *sperm*, nucleus is developing. In the ovary are one or several little rounded bodies called *ovules*. Inside each ovule an *egg*, or female cell, has been developing. The pollen tube grows down through the style until it reaches an egg in an ovule. Then the sperm nucleus

that had developed in the pollen goes into the egg and unites with the nucleus of the egg. This uniting of the nuclei of two cells is called *fertilization*. Fertilization occurs when an egg and a sperm cell unite and start a new individual.

After an egg cell has been fertilized, it begins to divide and make more cells. As a result of this cell division, a *seed* is produced. Let us now examine some seeds to discover their parts.

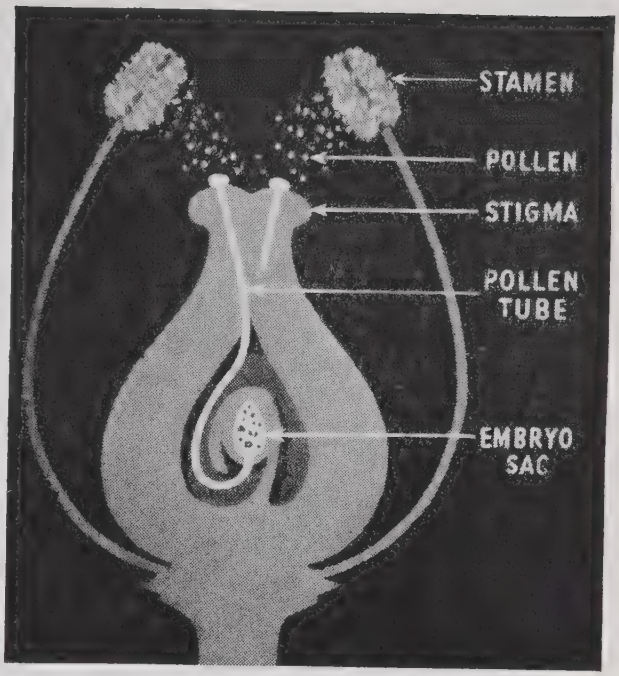


FIG. 342. If you can explain this picture, you understand how fertilization occurs in plants so that they can make seeds. (The egg cell is formed inside the *embryo sac*.)

EXPERIMENT 55. *What Different Parts Do Seeds Have?* Soak a handful of large dried lima beans and a handful of dried corn for about twenty-four hours.

a) Take a lima bean apart carefully. Lay the parts in a row on a sheet of paper so that you can label them. Notice the heavy seed coat that protects the *embryo*, or young plant.

b) To see the parts of a corn seed, lay a soaked grain flat on a board and cut it lengthwise from top to bottom. Use a safety-razor blade or a very sharp knife and be sure to cut exactly through the middle. Find the seed coat, the oily embryo with a tiny leaf and root, and the store of starchy food outside the embryo. Cut another grain crosswise. Does the corn grain have two separate halves as the bean does?

If you studied your bean and your corn grain with care, you discovered that each had a protective coat and an

FIG. 343. At the left are the two cotyledons of a bean seed. Next to it is a corn seed. At the right is a corn seed sliced lengthwise. In the uncut corn seed notice the shallow depression at the center. This is the tiny plant ready to grow (see Figure 344).

embryo. The embryo, or young plant, grew from the fertilized egg in the ovule. The seed-coat is the case that held the egg. A seed from any plant has these two parts. Some seeds, like the corn grain, have another part that contains a store of extra food.

You probably found that the embryo bean plant was made of several different parts. It had two large, hard parts that occupied almost all of the space in the seed. These were *cotyledons*. The cotyledons were filled with food for the young plant. Possibly there were several very tiny leaves at the growing tip of the young plant. A tiny stalk and a tiny root tip, that had scarcely begun to grow, completed the embryo. The corn seed was slightly different from the bean seed. On one side you found a shallow groove. This is the place where the young plant starts growing.

When you cut the grain lengthwise, you probably found a tiny pointed leaf and root just beneath the groove. The root was pointed toward the sharp end of the grain. The oily part of the grain is the single cotyledon of the corn seed.

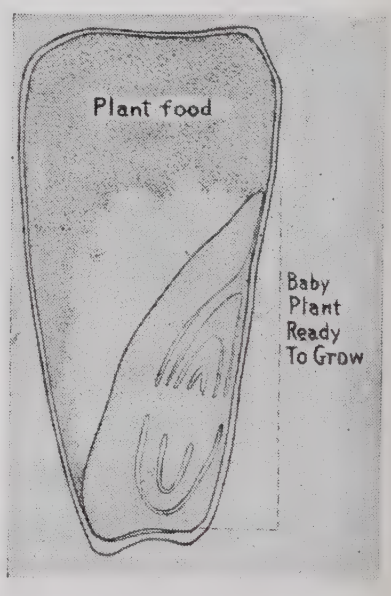


FIG. 344. Diagram of the inside of a corn seed

Around this oily part you found an even larger part filled with stored starch.

Cotyledons and other parts of seeds contain different kinds of food substances, such as starch, sugars, fats, and proteins. These stored substances provide food for the embryo when it starts growing again. They make the corn, beans, and peanuts that you eat taste good, and they furnish you with materials for energy and growth.

The number of cotyledons an embryo has helps *botanists* (people who study plants) classify plants. Plants whose embryos have two cotyledons are called *dicotyledonous* plants, and plants whose embryos have only one cotyledon are called *monocotyledonous* plants. Scientists often speak of these plants as *dicots* and *monocots* (*mono* means one, and *di* means two).

FIG. 345. At the left are the pussy-willow flowers that bear seeds. At the right are the pussy-willow flowers that produce pollen.

But not all plants bear *perfect flowers*. Perhaps you have noticed that all cottonwood trees do not bear the "cotton" that carries the seed. Early in the spring some cottonwood trees bear long, red catkins. These catkins have stamens but no pistils. Other cottonwood trees bear pistils but no stamens. Pollen from one tree is carried by the wind to the stigmas of the pistils on another tree. The cotton and seeds are developed on this tree. Flowers that do not have both the male and female parts are known as *imperfect flowers*. Pussy-willows and cat-tails are two more examples of imperfect flowers.

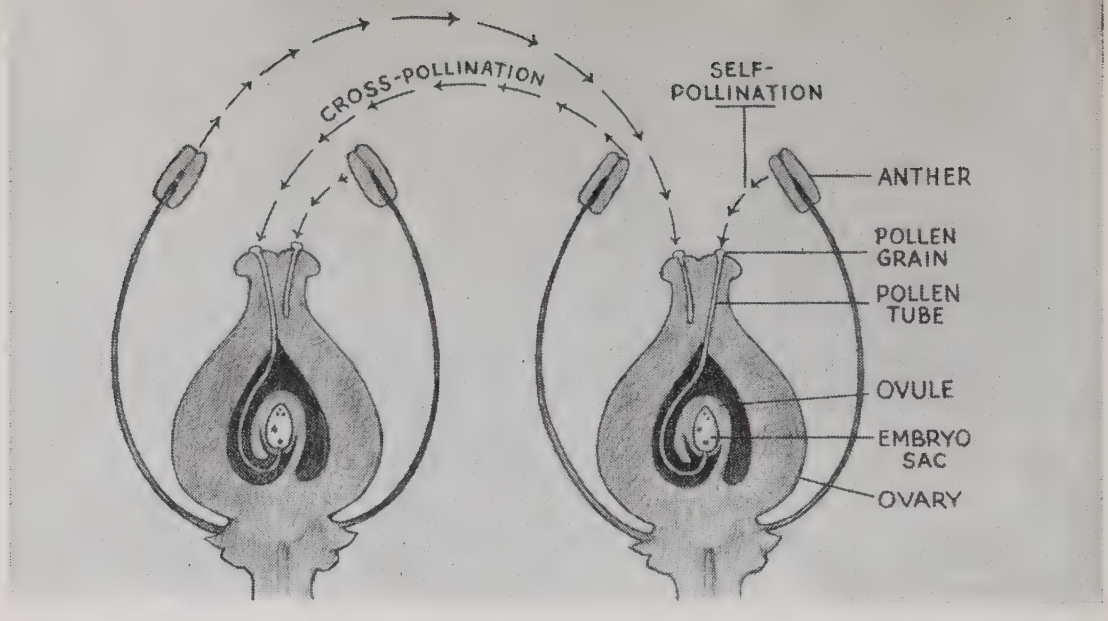


FIG. 346. When you have completed your study of seed-making by plants, you should be able to explain this diagram fully. Use the diagram to check your understanding of how plants make seeds.

Some perfect flowers, like those of wheat and sweet peas, have a covering over stamens and pistils. No pollen can escape from a flower of this kind, and no pollen from another plant can get in. So these kinds of flowers must provide their own pollen. When pollen from a flower falls on the stigma of the same flower, we say that *self-pollination* has taken place. Figure 346 will help make this clear to you. Even many kinds of flowers that do not have a covering over the stamens and pistils are able to pollinate themselves.

Often the pollen from a flower of one plant gets on the stigma of a flower from another plant of the same kind. *Cross-pollination* has then occurred. Cross-pollination is the only way in which plants with imperfect flowers can be pollinated. Many flowers are formed so that insects or wind will be almost certain to carry pollen from one flower to another. In many kinds of plants cross-pollination produces better seeds and therefore better plants. You will learn more about this in your later study.

Self-Testing Exercises

1. Name the parts of flowers that are actually necessary for reproduction. Name the parts that are not necessary.

2. Tell in your own words what happens in a flower that produces a seed. Name the flower parts that are used and tell the steps from the production of pollen to the production of seed.

3. Make diagrams of your own to show (1) how self-pollination occurs, and (2) how cross-pollination occurs. Compare them with Figure 346 to see if you are correct.

4. What is a seed?

5. What part of a seed helps botanists to classify plants into groups? Explain.

Problems to Solve

1. How are seeds like spores? How are they different? If you do not remember about spores, read pages 444-446.

2. Find in some good reference book the different ways in which flowers are cross-pollinated. Make a list of these ways.

3. Explain how insects help to pollinate flowers. Look in the encyclopedia and find why certain kinds of figs, clover, and yuccas could not reproduce if it were not for the help of certain kinds of insects.

4. Open the ovaries of several kinds of flowers to find how many seeds each can produce and how the seeds are arranged.

5. Watch such flowers as nasturtium, snapdragon, sweet pea, gladiolus, and clover to find how many insects and what kinds of insects visit them. Discover how those insects carry pollen from one flower to another and thus help to bring about cross-pollination.

HOW DO HIGHER ANIMALS REPRODUCE? Have you noticed during the study of this unit that reproduction in plants and animals is much alike? In one-celled plants and one-celled animals new individuals are usually produced by simple cell division. As you progressed in your study from lower to higher living things, the process of reproduction became more complicated. You found that some plants, the lily, for example, have both male and female parts in the same flower. Some kinds of animals, too, have

both male and female parts in the same individual. Earthworms and some kinds of snails are good examples of animals of this kind. Other kinds of animals have the male and female parts in different individuals, just as willow trees have.

Your study of this unit was so planned that you began with simple living things and went on to higher forms of life. The work was planned this way to help you understand better the more complex forms of reproduction that take place in higher plants and animals. As you study the more complex methods of reproduction, keep in mind that all methods are alike in one way: A bit of protoplasm is separated from a parent (or from two parents) and grows into a new organism like its parent. Now let us see how reproduction takes place in higher animals.

We shall begin with a small, fresh-water fish known as the shiner. The male shiner selects a still place in a gravel-bottomed stream. There he swims rapidly about and spreads his fins to attract his mate's attention. She swims into the nest and deposits eggs in the water. As she does this, he sends sperms into the water about the eggs. These sperm cells are so tiny that they can be seen only with the aid of a microscope. But under the microscope they are seen to have large heads and long tails. The tails lash about and push the sperms rapidly through the water. Since the sperms live for only a short while, they must find their way to the eggs very quickly, or fertilization of the eggs cannot take place.

When a sperm reaches an egg, the head of it pierces the egg wall. The sperm loses its tail, and the head part unites with the egg. Fertilization has taken place, and the eggs settle to the bottom of the water to hatch. The fertilized egg, as you have seen, contains bits of proto-

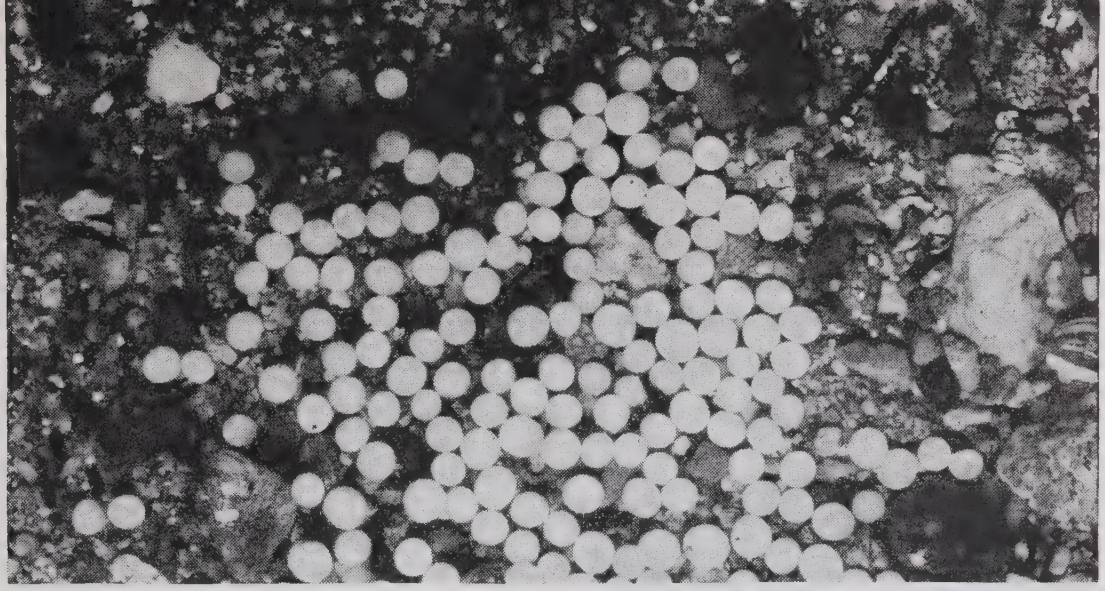


FIG. 347. In some basin-like part of a stream, where the water is quiet, the brook trout lays her eggs among the gravel. The eggs are then fertilized by a male fish.

plasm from both the male and the female. Because it received some protoplasm from both parents, the baby fish will in some ways be like its mother and in other ways like its father. Later you will learn more about how and why children resemble their parents.

Now let us think about the way young birds are produced. We shall take the robin as an example. Large egg cells containing stored food are formed inside the female robin in an organ called the *ovary*. When the pair of robins has made a nest, an egg leaves the ovary of the female and begins to move down a tube called the *oviduct*. Near the upper end of the oviduct it is fertilized by uniting with a sperm, which has been placed in the oviduct by the male. As the egg moves down the oviduct, additional food material (the white of the egg) is wrapped around it, and a shell forms around both the egg (which we usually call the yolk) and the added food. Then the egg is ready to be "laid" in the nest by the female.

One by one eggs leave the ovary, are fertilized, and laid, until there are several in the nest. The female then remains on the nest to *incubate* the eggs by keeping them warm with her body. Sometimes the male bird helps with this. While the eggs are kept warm, the protoplasm in each

yolk, or true egg, forms many, many cells. These grow, divide, and group themselves together until all the parts of a young robin are formed. Finally the young bird fills the whole shell and is strong enough to break out of the shell, or "hatch."

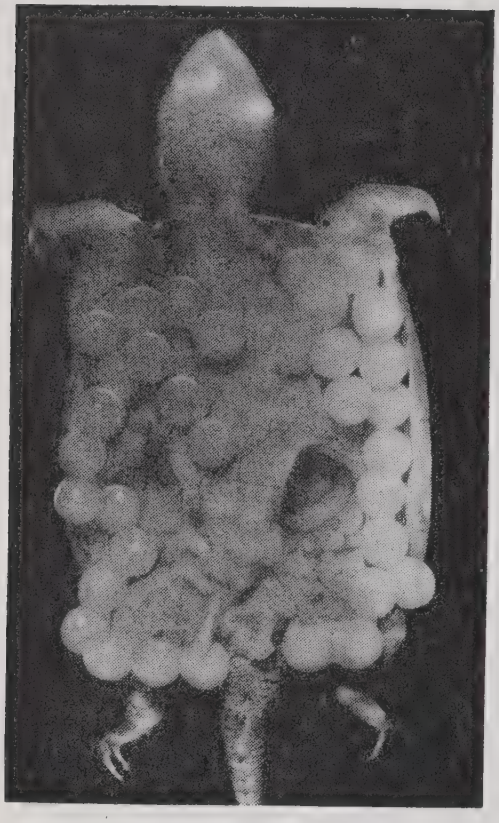


FIG. 348. All these eggs were found in the body of this female snapping turtle.

The process of reproduction is much the same with the robins as it was with the shiners. First, these animals select their mates. Then the sperms and the eggs are brought together. Finally, the young begin to develop. However, there is one difference in the mating of these animals—a difference so important that you should have it clearly in mind. The sperms and eggs of the shiners are scattered in the water. The sperms make their way to the eggs if possible; if not, fertilization does not take place. The eggs of the robin are fertilized within the body of the female. In this way reproduction is more certain.

This is true of all the highest types of animals: the eggs are fertilized in the mother's body. Not only is this true of birds; it is true of reptiles (turtles, snakes, and lizards) and of *mammals* as well. Mammals are a group of animals that (1) are warm-blooded, (2) have glands that supply milk to feed their young, and (3) have all or a part of their body covered with hair at some time in their life.

Now let us see how the animals known as mammals

produce their young. In early spring, rabbits, for example, select their mates, make nests, and begin to raise their young. The eggs are fertilized in the body of the female, as in the case of birds. But instead of being laid and hatched outside of the mother's body, as is true of the robin, the very tiny eggs are kept in her body. The young rabbits receive nourishment from the blood of the mother until they can live outside her body. Then they are born.

Most mammals, such as dogs, cats, moles, bats, squirrels, horses, cows, and man, produce their young in this way. But there is one kind of mammal that lays eggs, and the young hatch much as birds do. These animals are the duckbill and the spiny ant-eater of Australia.

Self-Testing Exercises

1. Why do the young of higher animals resemble both their parents?
2. Is fertilization in animals like fertilization in flowering plants? Give reasons for your answer.
3. In what way is reproduction different in the fish, the bird, and the mammal?
4. Why must eggs be incubated?
5. How can we tell mammals from other animals?

Problems to Solve

1. Read descriptions of egg-laying mammals in an encyclopedia. Compare these animals with other mammals.
2. Examine the body of a bat or read about bats in some good reference to find why these animals are not classified as birds.
3. Carefully break a hen's egg into a small dish. Notice how the shell is made to protect the growing chick. Look for a small white spot on the yolk. This spot contains the protoplasm that grows into a chick when a fertilized egg is incubated.
4. Some fish lay millions of eggs. Can you see why such a large number of eggs is advantageous?

FIG. 349. Cockleburs, shown at the left, have many little hooks that catch clothing and the hair of animals. At the right are tumbleweeds, common in our western plains states. In the fall, when the plant is dry and brittle, its stem breaks loose, and the plant is blown along by the wind, scattering seeds as it rolls along.

Problem 2:

HOW DO SEEDS GROW INTO PLANTS?

HOW ARE SEEDS SCATTERED? Everyone has seen the white head of a dandelion. This white head, as you know, consists of a great many tiny seeds with a bit of "fluff" attached to each. Now let us suppose that the seeds of the dandelion merely fell to the ground beneath the head. There would be so many seeds in such a small space that only a very few of them could possibly grow to mature plants. If seeds are to grow well, they must get away from the parent plants so that they can have food and room to grow.

You have seen hitch-hikers along the road so often that you probably pay no attention to them. But did you ever think of seeds as hitch-hikers? Many of them are. When you walk through fields and woods, seeds with sharp hooks or prickles often stick to your clothing. Later they are brushed off, or you pick them off. When they fall in

favorable places, they grow into new plants far from the parent plants. Seeds are often carried from place to place by sticking to the hair of animals. Some seeds of this kind are sand-burs, beggar's-ticks, Spanish needles, and cockle-burs. How many of these kinds of seeds grow near where you live?

Other kinds of seeds, particularly the ones in small fruits, are eaten by birds and other animals. Later they are dropped in waste matter given off from these animals' bodies. There they begin to grow, and in this manner the plants are spread. Seeds that are scattered by this means generally have very tough seed coats that keep the inner parts from being digested while the seeds are in an animal's digestive system. Try to think of some seeds that are scattered in this way.

Of course everyone has seen seeds scattered by wind. Dandelion, maple, elm, linden, thistle, ash, and clematis seeds are good examples. All of these seeds have "wings" or long, silky hairs to help them float in the air. Such seeds can travel great distances before they alight and start growing. Water, as well as wind, plays its part in helping to scatter seed. Bitter pecans, sycamores, and grass seeds float easily. They often fall into streams or are washed into them by heavy rains. The swift water then carries the seeds to a still place, where they are deposited and begin to grow. Look along the banks of streams or among the driftwood after the heavy rains, and perhaps you will find many other kinds of seeds that are carried by water.

One of the strangest ways of scattering seeds is found among plants whose seed-capsules explode and throw the seeds for considerable distances. A common example of explosive seed capsules is the jewel weed (balsam or touch-me-not). When the seed pods are ripe, they burst open and

scatter the seeds. The seeds of violets are also scattered in this way. Since you have studied why and how seeds are scattered, see how many examples you can find.

Self-Testing Exercises

1. Give at least two reasons why seeds need to be scattered away from the parent plant.

2. Make a list of ways in which seeds are scattered. Name seeds, in your locality, if possible, that are scattered by these methods.

HOW DO SEEDS GROW INTO NEW PLANTS? Before you begin to find out how seeds grow, think for a moment of what you know about seeds. You know that a plant does not begin its life as a seed. It begins as a single cell. The new plant really begins when a sperm from the pollen tube unites with an egg in the ovary of the plant. Then the fertilized egg must develop into an embryo within the parent plant. After seeds are mature, they are scattered and usually lie inactive, or *dormant*, until the beginning of the next growing season. *Germination* takes place when seeds begin growing after their dormant period.

EXPERIMENT 56. *How Do Seeds Germinate?* (*a*) Put some bean and corn seeds between several thicknesses of wet cloth. Put the cloth between two dinner plates, turning one plate upside down over the other. Keep the cloth moist until the seeds germinate. In this way you can observe the seeds without the soil being in the way.

b) Plant corn and bean seeds in small pots of earth so that you can watch them grow.

If you watched the seeds between the pieces of wet cloth, you saw them swell and split their coats. If you looked inside the seed, you found that the embryo was growing. The embryo used some of the food stored around it, and its cells began to divide. In both the corn and the

FIG. 350. Different stages in the growth of a bean plant and of a corn plant. What grows first from both seeds? What happens to the cotyledons of the bean seed and to the cotyledon of the corn seed?

bean the first part that grew out of the seed was the root. Small roots grew on the sides of the main root. Later many very small fuzzy-looking root-hairs appeared.

In the bean plants the cotyledons stuck to the stem and were pushed above the ground. The cotyledons stayed on the plant and provided food for it until the young plant could make its own food. In the corn plants the cotyledon stayed in the ground to give the young plant food until it was able to make food. A single shoot was pushed up out of the ground. All the time the cells in the young plants were dividing and adding more cells. Soon the plants of both kinds began to develop leaves. These turned green, and the young plants could then make food for themselves.

HOW DOES A PLANT INCREASE IN SIZE? Did you ever wonder how tender roots can push their way down into hard soil? Look through a microscope at a prepared slide showing a root tip. The cap of cells at the end is called the *root cap*. These cells protect the tender *growing point* as the root pushes down into the ground.

The growing point is where the root cells divide to form new cap cells and new root cells. The larger cells beyond the growing point merely get larger and help make the root longer. One layer of cells all around the root divides and grows to make the root thicker. So long as plants live, their roots continue to grow. Tiny new rootlets are constantly developing.

Fig. 351. Tip of a root

The long root-hairs shown in Figure 351 are very important. They are the cells that take in most of the water and dissolved minerals from the soil. These root-hairs develop near the tip of the growing root. As the root grows older, the old root-hairs wither, and the root becomes thick and hard and takes in little, if any, water. Now let us see how we can use what we have learned about the way roots grow and take in water.

First of all, what you have learned tells you that you must take care in transplanting a young plant. If you destroy the root-hairs, new ones must grow immediately, or the plant will die. In transplanting, therefore, you must remove some of the soil with the roots of the plant, because it is impossible to take the roots out of the soil without destroying the root-hairs. You should also pour water into the hole in which you place your plant. The muddy soil can more easily settle close to the root-hairs.

What you have learned also tells you how to water trees. Since the old roots take in little, if any, water, it does little good merely to water the base of a tree. The water, to be

of the most good to the tree, must fall on the soil in which the young roots and root-hairs are located. Therefore you must water around the tree for a distance of many feet.

You have learned that plant roots grow longer by forming new cells just back of the root cap. Now let us see how the stems of plants grow longer.

EXPERIMENT 57. *How Do Stems Grow Longer?* Get some young shoots from ash, buckeye, horse-chestnut, and other trees. Compare these shoots with Figure 352. Find the *terminal bud*, *lateral buds*, *leaf scars*, and *bud-scale scars*. How much growth did the shoot make last year? How old is the shoot? Cut open a terminal bud. What is inside it?

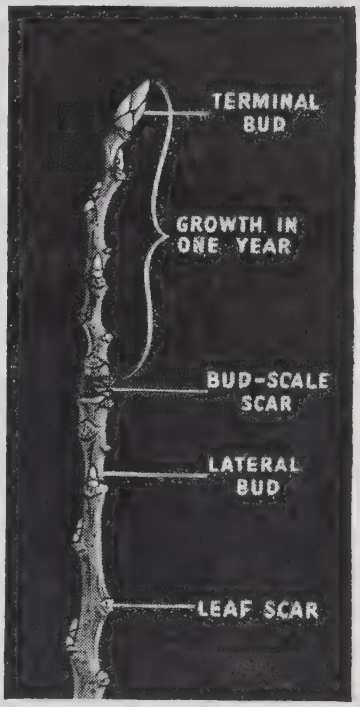


FIG. 352. Parts of a shoot in winter

When you cut open the *terminal bud*, you find small leaves. Back of these are growth cells much like the ones you saw in the diagram of a plant root. These cells divide to make new cells, and for a time in the spring they grow rapidly. Then they stop growing, and that part of the stem never grows any longer. Where the protecting scales fell from around last year's terminal bud, a ring-like marking, called the *bud-scale scar*, was left. The distance from this scar to the end of the shoot is the last year's growth of the stem. It will always remain the length it is after the season's growth has stopped. However, as you will soon learn, it can grow in diameter. You can tell the age of a shoot by counting the spaces between the bud-scale scars.

The buds along the sides are *lateral buds*. Some of these are *leaf buds;* others are *flower buds* (Figures 352 and 353).

The irregular scars mark the places where the leaf stems grew. The stems of plants that live only one year grow in much the same way except that their buds are continually growing until full size is reached.

Below the growing point of each stem most cells do not divide; they only grow larger until the stem has reached its full size. This is especially true of such plants as corn (Figure 355) and lilies. However, the stems of dicotyledonous plants grow larger in a different way.

Experiment 58. *How Do the Stems of Trees Grow in Thickness?* (*a*) With a sharp knife cut across a branch of a tree that is about one inch in diameter. Look for layers in the wood. Try to tear off some of the bark down to the white wood. Is there a layer where the bark pulls away from the wood easily?

Fig. 353. Section view of buds on a balsam poplar shoot

b) Repeat *a* with a branch that is only one-half inch in diameter. Does the smaller branch have as many layers as the large ones?

c) Examine the smooth top of a tree stump. How many layers can you find? If the tree has just been cut, look for the inner dark *heart-wood* and the light *sap-wood.*

When you examine large woody stems, you can find a dark inner part, the *heart-wood.* The heart-wood does not carry liquids up and down the stem, and it is often darker in color than the lighter wood around it. The heart-wood is really dead. The lighter wood is known as *sap-wood,* for it carries most of the liquid sap up the stem. Outside the

sap-wood is the bark that peels off rather easily. Between the sap-wood and the bark lies the *cambium*. The cambium is made of delicate growing cells that divide to form new wood and bark. The bark separates easily from the wood because the cambium cells are delicate and tear easily.

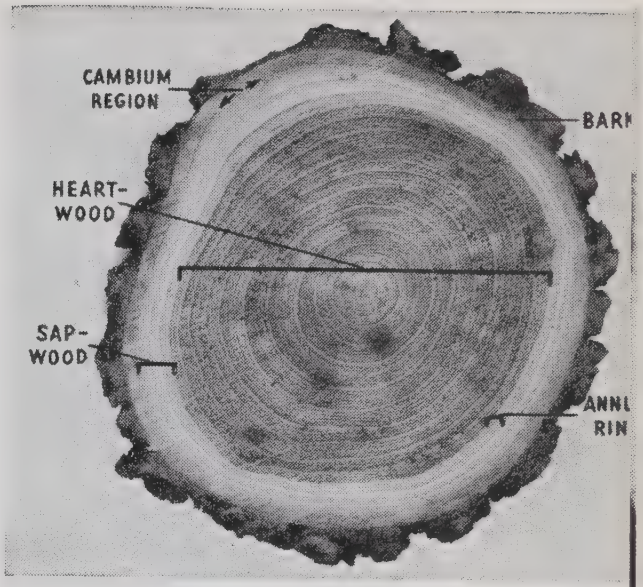


FIG. 354. Cross-section of a fifteen-year-old black locust tree trunk

As you already know, green leaves of plants use the sun's energy to make food from dissolved minerals, carbon dioxide, and water. The leaves get the dissolved minerals and water from the roots. This liquid material goes up to the leaves through tubes in the sap-wood. When the leaves have changed the raw materials into food, it goes back down through other tubes in the inner layer of bark to the cambium and other growing cells. The cambium uses manufactured food to make protoplasm for the new cells as the cambium cells divide and grow.

The fastest period of growth is in the spring, and the cells formed at this time are larger than those formed later in the summer. The difference in the size of the cells makes rings of different colored wood—a light ring for part of the year's growth and a dark ring for the other growth. These are called *growth rings*, or *annual rings* (Figure 354). You can count the annual rings and tell about how old a tree is. In places where there is moisture and warmth all year round, so that trees grow almost continuously, or in places where droughts occur often, so that trees frequently cannot grow, this method of telling the age of a tree is not

reliable. But in regions where there is summer and winter, the number of rings is an accurate record of a tree's age.

Stems are important to plants in two ways: (1) They support the leaves in the air and the sunlight, so that food can be made. (2) They carry water and dissolved minerals to the leaves for making food, and they carry the manufactured food to the different parts of the plants. Thus you can see that the stem must get larger as more leaves and roots are added to the plant by growth.

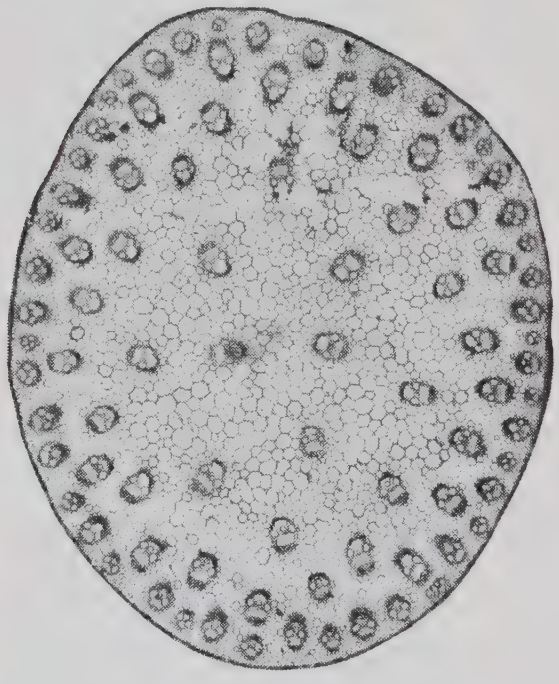


FIG. 355. The stem of a monocotyledon, like the corn plant, has no annual rings. The stem grows thicker by growing all through the inside as the size of the cells that make up the stem increases.

Self-Testing Exercises

1. Make your own definition of *germination*. Then check with the book to see whether you are correct.

2. What is the difference between the root cap and the growing point of a root? What does the root cap do?

3. What practical use can you make of what you have learned about the growth of roots?

4. Why do growth rings appear in tree trunks? How would growing conditions change the appearance of the rings?

5. How do the stems of plants grow longer?

6. How can you find out how old a twig on a tree is?

Problems to Solve

1. Why do plants often wilt after they have been dug up and planted in another place? How could you prevent this?

2. If you were to drive a nail into a tree trunk and leave it there for several years, would you expect to find the nail higher from the ground at the end of this time? Why?

3. Make marks with waterproof drawing ink one-fourth inch apart on a growing stem. Begin at the tip and mark back for a distance of ten inches or to the root of the plant. Each day measure the distance between the marks to see where the stem is growing.

4. If you can find the smooth end of a log or a stump, try to tell how old the tree was when it was cut down.

FIG. 356. The ancient cypress tree near Oaxaca, Mexico, is 160 feet high. It takes twenty-eight persons with outstretched arms and fingers to encircle the tree. Over four centuries ago Spanish explorers took shelter beneath it.

HOW LONG DO PLANTS LIVE? The oldest living thing in the world, so far as scientists know, is a cypress tree near Oaxaca, Mexico. This tree is estimated to be about 5000 years old. Of course, plants usually do not live nearly so long as that. If a scientist were asking the question at the beginning of this paragraph, he would ask it in a different way. He would probably say, "How long does it take plants to complete their *life cycles?*"

By "life cycle" we mean all the changes a plant goes through in the course of its development. Many seed plants complete their life cycles in one growing season or year. The seeds germinate; the plants produce roots, stems, leaves, and flowers; the flowers produce seeds; and the parent plants die. These plants are called *annuals*,

because they go through their life cycles in a single year. Wheat, beans, peas, and corn are examples of annuals.

Other kinds of plants require two growing seasons to complete their life cycles. Beets, for example, produce fleshy roots and leaves the first season. In the fall the leaves die, but the roots stay alive. In cold regions beets are dug up and stored where they will not freeze. If we want the beets to produce flowers and seeds, they must be planted again the next season. Plants that require two seasons to complete their life cycles are known as *biennials* (*bi* means two). Carrots, cabbage, hollyhocks, and certain primroses are also biennials.

What about trees and other plants that live for long periods of time? All plants that live more than two years are *perennials*. Apple trees, oaks, willows, dandelions, and the common milkweed are good examples of perennials.

Self-Testing Exercises

1. Make a diagram to show the life cycle of a bean plant.
2. Tell in your own words the meaning of *annual*, *biennial*, and *perennial*.

Problems to Solve

1. Make a list of some of the common annuals, biennials, and perennials in your community.
2. What is the oldest living thing in your community?

Problem 3: HOW DO ANIMALS GROW?

EARLIER in the unit you learned that higher animals, as well as higher plants, begin their lives as eggs. Each egg must be fertilized by a sperm; then the young animal begins to develop. In studying this unit you found that it was impossible to think clearly about reproduction without also thinking about growth, for growth begins as soon as an egg is fertilized. In this problem you will begin

FIG. 357. The lamb looks enough like its mother so that you can tell what kind of animal it is. What changes will take place in the lamb as it grows into an adult sheep?

with the fertilized egg and find how some of the different kinds of animals grow.

HOW DOES A CHICKEN GROW? A very young chick is covered with down and is much smaller than a grown chicken. Yet it is so much like a grown chicken that you have no trouble recognizing it. Kittens and puppies resemble grown cats and dogs, and babies are enough like grown men and women for us to tell whether they are cats, dogs, or human beings. Animals of these kinds go through gradual changes as they grow, until finally they are adults.

Let us study the chicken as an animal of this kind, because hens' eggs are quite easy to examine as they develop. Wouldn't you like to have a hen's egg with a window in it so that you could see what happens to a chick as it grows? Scientists have really cemented windows in the shells of eggs and have watched the chicks develop. But you will find it better to study the development in a different way.

EXPERIMENT 59. *What Happens to an Egg as It Develops into a Chicken?* Put a dozen or more fertile eggs into an incubator or under a setting hen. On the third day after you have

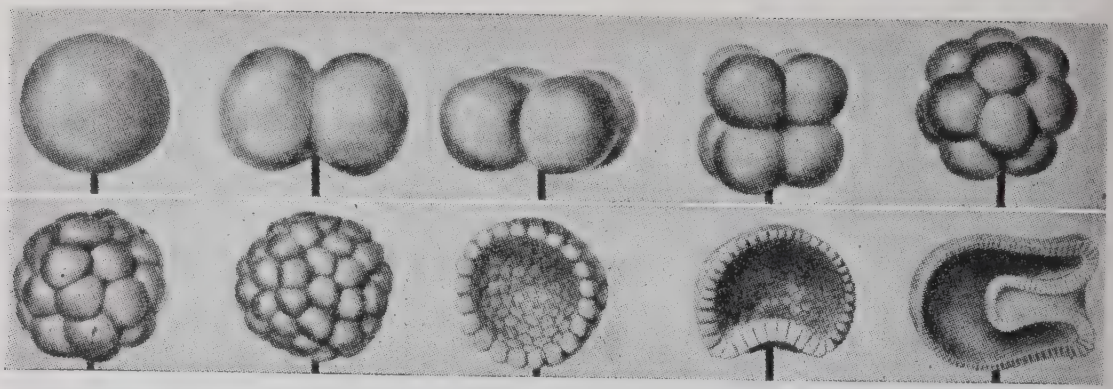


FIG. 358. These models show how the fertilized egg cell of the starfish divides to make many cells, how these cells form a hollow ball (shown cut in half), and how the hollow ball folds in to form layers of cells. Chickens, snails, human beings, and many other kinds of animals begin their growth in this way. (Jewell Models)

started the eggs, break one into a very weak solution of salt water that is at about body temperature. What has happened to the egg? Can you find the spot where the chick's body has started to develop? Can you see the heart beating? Why do you think the blood vessels are being sent out over the food material?

Break and examine an egg on the sixth, ninth, twelfth, and fifteenth days. Keep a careful record in your note-book of the changes that have taken place. Make drawings each time, showing the different parts with colored crayons. Compare your notes and your drawings from time to time.

A small fertilized egg, like that of a snail, is shaped much like a tiny ball. First it divides into halves that stick together. Each half is a cell. Soon these two cells divide again, and the egg has four cells. Division continues to take place, and the egg has eight cells, then sixteen, and so on. As the cells of the egg go on dividing, they are still grouped in the shape of a ball.

The inside of this ball of cells gradually becomes hollow. Then a peculiar thing happens. One side of the hollow ball of cells begins to push in much as if you took your finger and pushed in one side of a hollow rubber ball. This con-

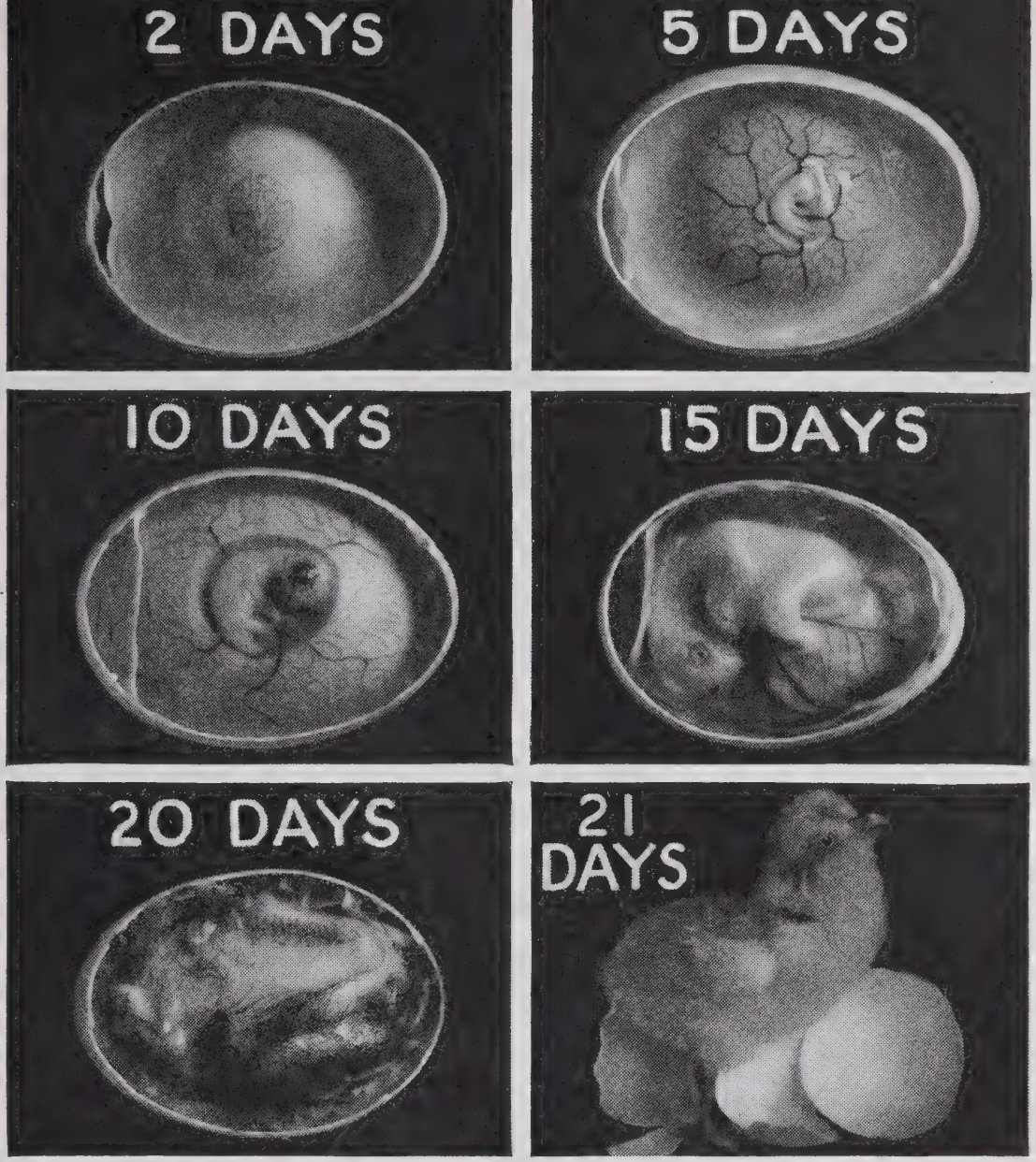


FIG. 359. Several stages in the development of a chick from an egg

tinues until the ball is so pushed in that it looks like Figure 358. The egg now has two different layers, due to its pushing in. Then a third layer develops. It is from these three layers that the different parts of the body develop. Muscles, blood, and blood-vessels grow from the middle layer. The outer layer develops into the skin and nervous system, while the linings of the digestive system, the liver, the lungs, and other organs, develop from the inner layer.

The chick develops in a somewhat similar manner from a layer of cells that form on one side of the yolk or egg. However, the stages of development are quite different in

appearance because so much food is stored in the hen's egg. All the time the chick's body is developing, it is using the food stored in the egg. The egg has plenty of moisture in it, and you keep the temperature of the incubator at about 103° F. to provide the proper temperature for growth. If you did Experiment 59 carefully, in about twenty-one days the chicks hatched. And then you had to provide the proper food and living conditions in order for the chicks to continue growing.

The newly-hatched chick has a soft body covering of down. As its body grows, it sheds this covering and gradually grows feathers. Chickens and other birds generally shed their feathers (*molt*) in the fall and grow an entirely new set. As the chick molts, grows new feathers, and increases in body size, it becomes a grown, or adult, chicken. All of the time the cells of its body are dividing and making new protoplasm from the food it eats.

The young of such animals as dogs, cats, rabbits, wolves, horses, cattle, and even man, go through a similar kind of development during the embryo stage. However, the development of the embryo takes longer for some animals than it does for others. Table 4 shows you how long it takes, from the time the eggs are fertilized, for the young to be hatched or born, as the case may be.

TABLE 4. LENGTH OF TIME REQUIRED FOR EMBRYOS TO DEVELOP

Kind of Animal	Length of Time for the Embryo to Develop	Kind of Animal	Length of Time for the Embryo to Develop
Robin	14 days	Dog	62 days
Pigeon	16-17 days	Pig	4 months
Chicken	21 days	Cow	9 months
Rat	21-28 days	Man	about 9 months
Duck	26-28 days	Horse	11 months
Rabbit	30 days	Elephant	2 years

FIG. 360. This is an enlarged picture of young trout still attached to the egg sacs that supply food for them until they are able to find food for themselves.

All of the animals listed in Table 4 have backbones. They are classified as *vertebrates*. (Look at Figure 270, page 355, so that you will understand where the word vertebrate comes from.) They have many body structures that are alike, and many of the stages of their growth are alike. However, there is one important difference among them. Some of the vertebrate animals lay eggs, and the young hatch from the eggs. Such animals are *oviparous* (egg layers). Other animals give birth to their young. These are *viviparous* (giving birth to living young).

Now let us see how human beings grow. In general, we follow the life cycle that you have just studied. But, of course, it takes man longer to go through his life cycle than it does many other animals. Each of us began life as a single fertilized egg cell. This cell divided and formed others. The cells gradually formed into a hollow ball, like the one described on page 476. Then one side of the ball pushed in, making two layers, and soon a third layer developed. Different organs of our bodies developed from these layers. In from 270 to 290 days we were ready to be born.

FIG. 361. These X-ray photographs of the hand of the same child at the age of six and at the age of twelve show how some of the cartilage has been replaced by bone.

Did you ever see a very young baby? How helpless it was! You were like that when you were very young. You had no teeth, and probably you had very little hair on your head. You were in a period of your life cycle known as *infancy*. During this time you kept right on growing. You got taller and stronger. More hair grew on your head. Before long you began to develop your first set of teeth. But you did not keep these teeth very long. In the second period of your life, known as *childhood*, your first set of teeth began to come out, and others grew in their places.

Many other changes had taken place since you were a baby. The length of your legs and arms increased in proportion to the length of your body. Your face changed from the rounded face of an infant to the oval-shaped face of a child. The ends of your bones and other places in your body were made of a flexible substance known as cartilage. This cartilage was gradually replaced by bone as you grew (Figure 361). This replacement is still going on in your body today, and your bones will continue to change until you are old.

When boys and girls reach the period where they are changing into young men and women, we say that they are *adolescent.* Next they are young men and women, then they are middle-aged, then old. Human beings grow very fast until they are mature. Then their growth slows down, until finally it stops. After several years their bodies slowly become less strong and vigorous, and later they die. The table below will give you some idea of the length of life of the animals you studied in Table 4.

TABLE 5. LENGTH OF LIFE OF SOME COMMON ANIMALS

Kind of Animal	Usual Age	Kind of Animal	Usual Age
Robin	8-9 years	Dog	10-12 years
Pigeon	20 years	Pig	20 years
Chicken	2-3 years	Cow	12-16 years
Rat	8-9 years	Man	About 60 years
Duck	3-3½ years	Horse	25-30 years
Rabbit	5-7 years	Elephant	100-200 years

Self-Testing Exercises

1. Use a ball of clay to illustrate the early stages in the division of an egg: two cells, four, eight, etc.

2. Get a hollow rubber ball and use it to show how an embryo develops two layers of cells.

3. Tell in your own words the difference between oviparous and viviparous animals. Give examples of each kind of these animals that are found in your locality.

4. Describe the different periods in the life cycle of a human being. In your description tell about two things: the appearance of the individual and what the individual can do or cannot do.

5. Explain how cartilage changes as a child grows older.

Problems to Solve

1. Make a list of ways in which a baby or a young calf is like its parents. Give ways in which it is different.

2. Make a list of vertebrate animals found in your neighborhood. Make a list of animals that are not vertebrates.

HOW DO ANIMALS DEVELOP BY METAMORPHOSIS? In the part of the unit that you have just studied, you learned that the young of some kinds of animals look enough like the grown, or adult, animal so that you can easily tell what kind of animal it is. Now let us study some kinds of animals that are different. Did you ever see a tadpole? It does not look much like a frog. If you did not know what a tadpole was, you would not recognize it as the young of a frog.

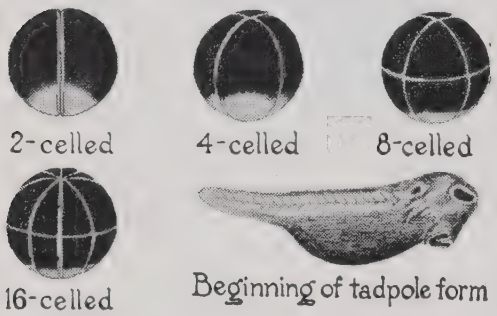


FIG. 362. Several of the first stages in the development of a frog's egg

EXPERIMENT 60. *How Do Frogs Develop?* If possible, get some frogs' eggs and keep them in a large aquarium of pond water where there are plenty of plants. Examine the eggs every day with a hand lens to see how they develop. In your note-book keep a record of what you see to help you remember what changes take place. Make sketches, if you can, to show these changes. Be sure to put the date on each of your sketches.

In the early stages of development a frog's egg first divides into two cells, then four, eight, and so on, as you have already learned (Figure 362). Soon the young fish-like embryo can be seen inside the jelly that surrounds the egg. When the embryo has grown into a tadpole, it breaks out of the jelly that surrounded it. If you watch closely, you may see the embryo wiggle about. It lives for a few days on a part of the egg material that is left in its body; then it begins to feed upon tiny plants and upon other vegetable matter.

At first a tadpole has branched tree-shaped gills on either side of its head. These disappear later, and gills

develop inside the body to take oxygen from the water. Soon hind legs begin to develop, and the large tail begins to get smaller. It is gradually absorbed into the body to be used as food. Air-breathing lungs develop to take the place of inside gills. Watch to see when the tadpoles in your aquarium come to the top of the water to breathe. When they do this, they have developed air-breathing lungs and are using them. Finally the front legs appear, the tail is all gone, and the tadpole has become a frog.

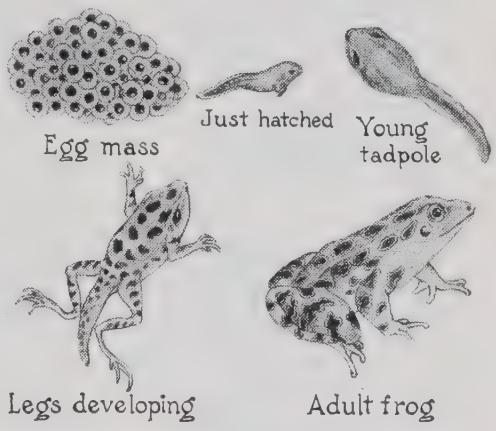


FIG. 363. The series of changes through which a frog goes in becoming an adult

Instead of developing gradually from a tiny creature that resembled its parents, the frog went through several different stages in its growth (Figure 363). During each of these stages the growing tadpole did not look at all like a frog. Such a series of changes in a developing animal is known as *metamorphosis* (change of form).

Now let us see what stages a frog goes through in becoming grown. First, it is an egg, then a tadpole, and finally a frog. Perhaps you noticed that a tadpole is fitted to live in a different environment from that of a frog. A young tadpole has gills with which it can get oxygen from the water. It also has a tail to propel itself through the water. The frog, on the other hand, has lungs to get oxygen from the air, and legs by which it can both move on land and swim in the water.

Not all frogs go through these changes in the same length of time. The changes vary with the kind of frog and the kind of season. Frogs' eggs are generally laid in

March or April. Can you see how a very cold or a very dry season would affect the development of frogs' eggs?

Many other kinds of animals also grow by metamorphosis. Examples of such animals are toads, newts, and insects. Insects do so much damage to our food crops and their stages of development are so different from those of frogs that we shall study a few examples of insect metamorphosis. Grasshoppers are a good example of one kind of insect metamorphosis, and they are easy to observe (Figure 364).

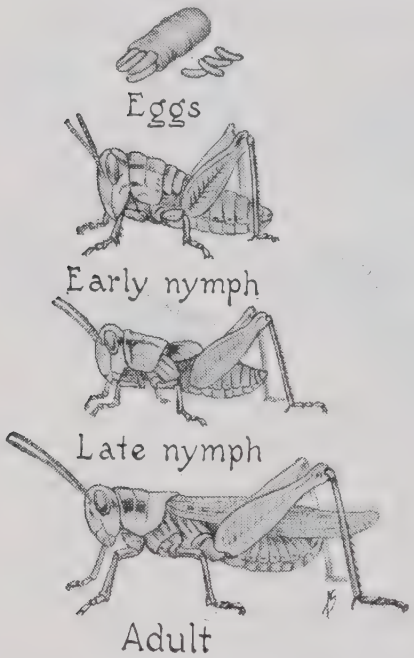


FIG. 364. The stages in the growth of a grasshopper. Notice that wings are beginning to grow in the late-nymph stage.

Grasshoppers are first eggs. These eggs develop into tiny grasshoppers that are much like the adults except that they have no wings. These immature grasshoppers are called *nymphs*. Nymphs always seem to be hungry. They eat heartily for several days, and during this time their bodies grow considerably larger.

But the bodies of grasshoppers are not covered with skin that will grow as their bodies grow. They are covered with a substance known as *chitin*. It is similar to the substance your finger-nails are made of. So, as they grow, grasshoppers simply burst their body coverings and shed them. We say that the insect *molts*. A new covering of chitin develops, and the nymph begins to eat heartily again. After about five molts, the grasshopper has developed wings. It is then a full-grown insect.

Grasshoppers go through three stages in their develop-

ment: *egg*, *nymph*, and *adult*. Such a type of metamorphosis is known as *incomplete metamorphosis*, because some other kinds of insects go through more complete changes during their life cycles, as you will now learn.

Such insects as moths, butterflies, bees, ants, wasps, house-flies, and many others, go through very definite changes as they develop (Figure 365). But the changes in their life cycles are entirely different from those of grasshoppers.

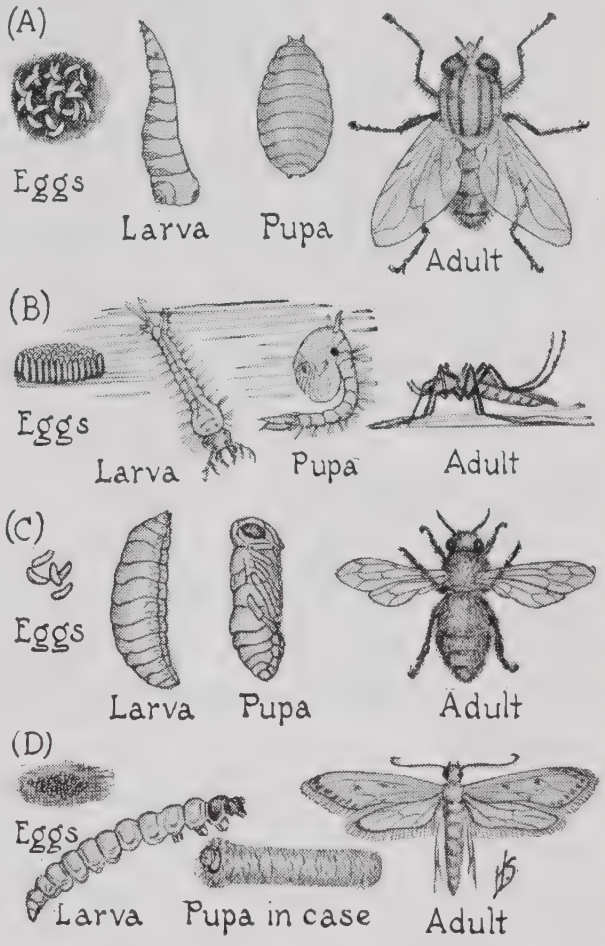


FIG. 365. Complete metamorphosis of the (A) house-fly, (B) mosquito, (C) honeybee, and (D) clothes moth

The eggs of moths hatch into worm-like creatures known as *larvae* (*larva* is singular). You probably call them caterpillars, or "worms." Larvae have enormous appetites and eat greedily for short periods of time. Soon they spin silken cases about themselves and go into a resting stage. During this stage they are known as *pupae* (*pupa* is singular).

The silken case around the pupa of a moth is known as a *cocoon*. Have you ever found cocoons hanging on branches of trees? Moths generally spend the winter within the protective covering of their cocoons. By spring the pupa in the cocoon has developed until it is ready to

"hatch." Then it comes out of the cocoon as a fully developed, adult moth.

Butterflies and other insects go through the same stages while they are growing. However, butterflies, bees, ants, and other insects do not spin cocoons. They develop hard cases about themselves for their resting stage. These are usually known simply as pupae.

The insects you have just been studying go through four distinct life stages. These stages are egg, larva, pupa, and adult. Insects that go through these stages of development have *complete metamorphosis*. If you will watch, you will see many other examples of both incomplete and complete metamorphosis taking place about you during the growing season.

Self-Testing Exercises

1. Make an outline of the stages frogs go through as they grow from egg to frog. From your outline tell the story of their development.
2. Why does a tadpole not begin eating when it is first hatched?
3. Make your own definition of the word *metamorphosis*.
4. Make a table to show the different stages in the metamorphosis of (1) a frog, (2) a moth, (3) a grasshopper.

Problems to Solve

1. Is it possible to drown an adult frog? Give reasons for your answer.
2. Compare the molting of a grasshopper with the molting of a chicken. Does the word "molt" mean the same in the case of each animal?
3. Make a list of common insects of your neighborhood. Opposite the name of each insect write the kind of metamorphosis it goes through.

LOOKING BACK AT UNIT 10

1. Copy the headings of each of the sub-problems in the unit. For example, the first sub-problem heading on page 442 is "What is the simplest way in which plants and animals reproduce?" Write in a few sentences the answer to each sub-problem. This exercise is planned to help you get a more complete picture of how life continues upon the earth.

2. Show that you know the meanings of the following words:

reproduction	*mycelium*	*fission*
spore	*fertilization*	*seed*
egg	*dicotyledonous plants*	*sperm*
embryo	*germination*	*incubate*
perennials	*pistil*	*biennials*
ovary	*regeneration*	*pupa*
life cycle	*metamorphosis*	*cambium*

ADDITIONAL EXERCISES

1. Get 100 seeds of the same kind. Put them between pieces of wet cloth and place the cloth between dinner plates, as you did in Experiment 56. Keep the cloth moist and the plates in a warm place. After several days count the number of your seeds that germinated.

2. Spores of mushrooms are of different colors. The color of the spores helps to tell the kind of mushroom. Make a spore print by cutting the "cap" from a "toadstool" and laying it with the "gills" down on a smooth, white piece of paper. Cover the cap and paper with a dry tumbler to prevent the spores from blowing away. In from twenty-four to forty-eight hours the spores will fall from the gills and make a print.

3. Find out what insect galls are. Make a collection of them. Look in some good reference and try to find what insect made the gall. Mount the galls and write a brief description of the insect that caused them.

4. During the winter and early spring see if you can find cocoons of moths on trees and shrubs. Bring them into the

house and keep them in large jars with soil in the bottom. The soil should be kept moist. When they begin to come out, provide sticks for the moths to climb on while their wings expand and dry. If you wish, learn how to kill and mount the moths.

5. Mount several kinds of twigs on a chart. Label them to show the main parts and indicate the amount of growth made by them each year as far back as you can count.

6. From the proprietor of a seed store find out about the length of time it takes for different flower and garden seeds to germinate. Arrange your facts in a table.

7. Why should the grains of corn be planted a long way apart in the field?

8. Ask your neighbors to tell you the age of the oldest living thing they know, for example, a cat, a dog, a tree, etc.

9. In a reference book find out how some of the one-celled bacteria and molds are useful to man. For example, look up cheese-making, yeast, butter-making, and vinegar-making. Perhaps you can get a copy of a book called *Bacteria, Yeasts, and Molds in the Home,* by H. W. Conn.

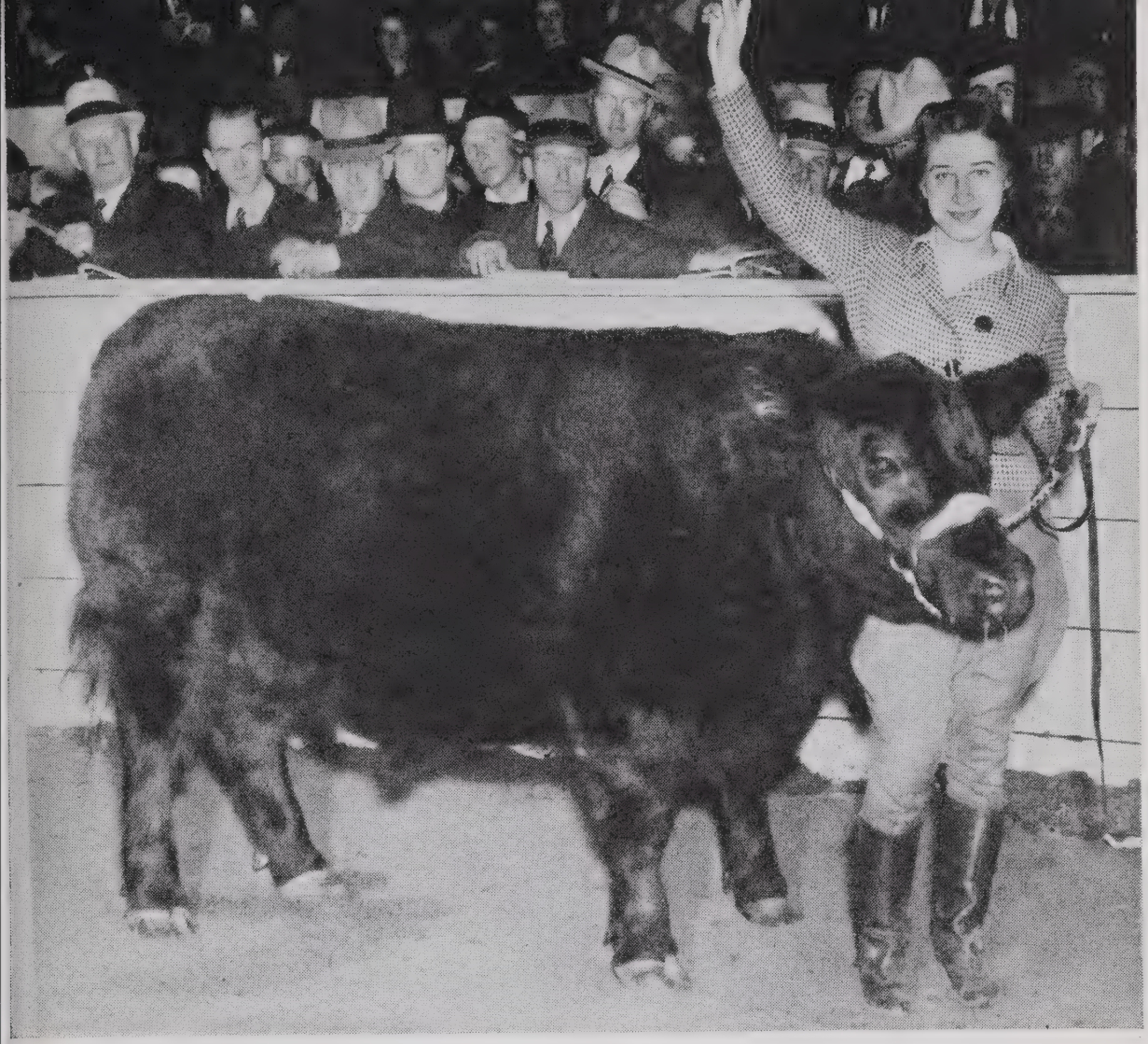


FIG. 366. At the great International Livestock show at Chicago this fine steer, owned and raised by a fourteen-year-old Illinois girl, won the grand championship as the finest farm animal exhibited. Would you know how to feed and care for such an animal?

To feed our people and some of the other people of the world, our farmers grow each year nearly 500,000,000 bushels of potatoes, more than a billion bushels of corn, over 500,000,000 bushels of wheat, over 100,000,000 bushels of apples, and nearly 50,000,000 bushels of peaches, to say nothing of such other crops as oats, hay, rice, pears, grapes, and cherries. Also on the farms of our country are about 12,000,000 horses, 70,000,000 cattle, 50,000,000 sheep, 40,000,000 hogs, and countless chickens and other fowls.

Farming is a big business, and it is a scientific business, too. All these plants and animals that we need so much must be taken care of in a scientific way. Poor crops and sick animals mean loss to the farmer and less food for our people. In this unit you will learn how scientists help the farmer raise strong, healthy plants and animals.

UNIT ELEVEN

UNIT 11

HOW DOES MAN TAKE CARE OF THE PLANTS AND ANIMALS HE USES?

INTRODUCTORY EXERCISES

1. Under what conditions do plants grow best?

2. What is soil made of? Turn back to pages 130-135 of Unit 3 if you need help with your answer.

3. If you live on or near a farm, make an outline of the important steps in the care of some crop, such as corn, wheat, or cotton. Begin with the preparation of the soil and end with the storage or preparation of the crop for marketing. If you do not live on a farm, talk to someone who knows about farming and get the information you need from him. Leave spaces in your outline for Exercise 4.

4. After each step in your outline in Exercise 3, write a sentence telling older ways of doing the work. Then write a sentence telling newer ways. An example follows:

Old Way: Plowing a single furrow at a time with a hand plow pulled by a horse or a mule.

New Way: Plowing two or more furrows at a time with a tractor and a gang-plow.

*5. What is the *food cycle* in nature?

*6. What are *legumes*, and how do they help other plants?

7. Give an example to show that you know what crop rotation is and why it is practiced.

8. List the insects that do the most damage to crops in your locality. After the name of each insect, write a sentence telling the methods used in trying to control it.

9. List the important animal diseases that occur in your locality. Tell how each disease is treated.

10. Tell how a hotbed or a greenhouse provides proper growing conditions for plants in cold weather.

11. What sanitary conditions must be provided in a dairy barn or a poultry house?

FIG. 367. If you live on a farm, perhaps you belong to a 4-H club. Nearly two million farm boys and girls throughout our country belong to these clubs. The club members are learning to be scientific farmers, and their pledge is this: "I pledge my head to clearer thinking, my heart to greater loyalty, my hands to larger service, and my health to better living for my club, my community, and my country." In this picture a club leader is showing some Iowa club members how to select the best ears of corn for seed for next year's crop.

LOOKING AHEAD TO UNIT 11

IT IS FIVE o'clock in the morning. The place is the home of Farmer Brown. The alarm clock tells Jim that it is time to get up, but he turns over and promptly falls asleep again. Then dimly he feels that something is happening, and he discovers that his father is shaking him and saying, "Time to get up, Jim. We have lots to do today."

By the time Jim is dressed, he can hear his mother in the kitchen, getting breakfast. His father has already gone to the barn. Hurriedly he dresses, splashes his face with cold water, and joins his father in the barn. His father is milking. The horses greet Jim with a neigh of welcome as he pours a generous portion of oats into their feed boxes. While the horses are eating, he cleans out their stalls and puts their harnesses on. In the meantime his father finishes the milking and is ready to run the milk through the

FIG. 368. Before a farmer can plant a crop, he must *cultivate* the soil. Cultivating the soil means breaking it up into small pieces and loosening it so that the seeds can be put into the soil and so that roots and stems can grow easily.

separator to get the cream out of it. While Jim is turning the handle of the separator, he hears his mother call, "Breakfast is ready." You can guess what Jim does then.

After breakfast the real work of the day begins. First, the hotbeds are uncovered to let in the sunlight. Then the hogs and chickens are fed, and the cattle are let out in the pasture. The horses are hitched to a plow, for Jim's father is going to plow in the east twenty acres today. Jim is too small to follow a plow, but his father wants him to finish planting the garden at the side of the house. And so the day wears on. At noon there is a pleasant interruption for dinner. Then the plowing and gardening are continued until the sun begins to sink low in the west.

Now the evening chores must be done. Jim mounts his pony and goes after the cows. His father unharnesses the horses, feeds them, and brings in straw from the straw stack for them to lie on. By this time Jim is back with the cows. He and his father carefully measure out the food for each cow and then begin the evening milking. Once again Jim turns the separator, and once again he is glad to hear his mother call "Supper is ready."

FIG. 369. Here is a Missouri 4-H boy with his fine pure-blooded hogs. He knows just how to feed and care for them so that they will grow strong and fat, and perhaps win a prize at the county fair.

The day's work is really over. Jim thinks that he would like to read, but soon his head is nodding. "Better go to bed, Jim," says his father. "We have lots of work to do tomorrow." Jim goes upstairs, undresses, tumbles into bed, and soon is fast alseep. It seems to him that almost immediately he hears, "Five o'clock, Jim. Time to get up." Another day has begun.

Perhaps you think from this description that farming is hard work. And so it is. But doing the chores, planting and harvesting the crops, and caring for the animals are only part of the work of the farmer. These tasks can all be done with the muscles of the body. With a little practice anyone can learn to do them.

The most difficult and important task of the farmer is to plan what he shall do with his farm. Shall he plant the west twenty acres in corn or wheat? Last year the "east twenty" did not raise good corn. Should he change his crop, or should he fertilize the soil? Should he plant his corn now, or should he wait a little longer? The hens are not laying many eggs. Is it the kind of feed he is giving them? Or are they troubled with pests or disease? What

FIG. 370. These scientists are analyzing soil to find whether it contains the elements that crops need to make them grow well. Can you read some of the words in the sign on the wall? Later in this unit you will learn how farmers keep the soil supplied with the elements and compounds that are necessary for good crops.

had he better do about it? These and dozens of other problems are constantly in the mind of the farmer. What should he do?

Fifty years ago the farmer had very little exact information to use in solving his problems. He learned from his own experience or the experiences of his father or of the neighbors. Some of his information was fairly reliable, and some was not. Farming was largely a "hit or miss" business.

Now, however, the situation is different. No longer is it necessary for a farmer to rely wholly on his own experience or on what the neighbors think. Science has entered the field of farming. The United States Government has a Department of Agriculture, employing chemists, botanists, zoologists, physicists, geologists, and bacteriologists; in fact, the Department of Agriculture employs experts from every field of science. The states have agricultural experiment stations, each station directed by a staff of

experts. The farmer puts his questions to these investigators. They carry on controlled experiments all over the country, and many of the farmer's problems are solved for him. Others may be answered only after years of study.

In this unit you will learn how the farmer takes care of the plants and animals that he raises. You will see how the many principles of science that you have learned have been applied to making farming a really scientific occupation. You will understand more fully just what must be known and done in order for you to have your three "square" meals each day.

Problem 1:

HOW DO FARMERS IMPROVE THEIR SOIL?

In your study of science you have already learned that all food of living things is made by green plants when the sun shines on them. The materials that the green plants use to make food come from the soil and the air. To grow well, plants must have good soil. Thus the farmer's soil is his most valuable possession. If he is wise, he gives much thought and time to the care of his soil.

A good soil has the right amounts of sand, clay, and humus, as you learned in Unit 3. Such soil breaks up easily and remains loose, so that plants can grow well in it. Loose soil allows air to reach the plant roots. Good soil contains plenty of the minerals that plants need to make food for themselves and for us.

Yet, without the right amount of moisture even the best of soil is worthless for farming. Careful experiments show that the soil must furnish very large amounts of water to grow the common crops. For example, in one series of experiments 368 pounds of water were needed to produce a pound of corn, 513 pounds of water for a

pound of oats, and 736 pounds of water for a pound of beans. Each day an average crop is growing actively, its roots must receive from the soil six tons or more of water per acre. No wonder, then, that moisture is one of the big problems in farming.

HOW DOES WATER ACT IN THE SOIL? Before you can understand how the farmer solves the problem of moisture in the soil, you must know how water acts in the soil. You can best understand how water acts in the soil if you examine some soil that contains different amounts of water.

EXPERIMENT 61. *How Does Soil Behave When It Contains Different Amounts of Moisture?* Obtain samples of loam or clay soil as follows: (1) soil that has been allowed to lose all the water it will by evaporation; (2) soil in which plants are growing—neither very dry nor very wet; (3) soil that has had water poured on it until it will hold no more.

Try to break up each kind of soil with your fingers. How does each behave? Try also to stick different parts of it together. Look for air spaces in each sample of soil. In which condition do you think soil could best be prepared for planting seed?

Now let us see what happens to the growth of plants when the amount of moisture in the soil is not correct. An experiment will show this clearly.

EXPERIMENT 62. *How Is the Growth of Plants Related to the Amount of Water in the Soil?* Get three one-pint cans and punch several nail holes in the bottom of two of the cans. Fill the cans with soil and plant several grains of corn in each one. Give Can Number 1 a tablespoonful of water every day. Give Can Number 2 one-fourth cup of water every day. Can Number 3 should be the one with no nail holes in the bottom of it. Keep the soil in this can soaked with water, so that the water stands above the level of the soil.

FIG. 371. A low piece of land like this one is known as a *frost pocket.* Water does not drain easily from it, and the wet soil stays cold because water is evaporating from it and because wet soil does not get warm as quickly as dry soil. Also, cold air settles into this low place. Plants such as fruit trees and bushes, which need warm soil and air, cannot grow well in a place like this.

Continue giving the amounts of water suggested on page 496 for two weeks. What are your conclusions? Write the results in your note-book in brief form.

As you have learned, most plant roots need air. When the soil is saturated with water, such plants cannot grow, because the water fills up all the air spaces. And if the soil stays saturated long enough, the plants die. Soil that is cultivated when it is full of water often becomes so hard when it dries that it can hardly be broken up again. Soil that is neither too wet nor too dry is most desirable in every way. As you noticed in Experiment 62, such soil seems to have a little moisture all through it, yet there are air spaces between the soil particles.

Have you ever noticed how a thin film of moisture sticks to a rubber ball that has been dropped into water? The film of moisture is held by the force of adhesion (page 238). When the soil is neither too wet nor too dry, it is like many tiny, wet, rubber balls in a container. The wet particles touch each other, and the films of moisture help

FIG. 372. At the right end of this drawing are shown moist soil and saturated soil as they might look under the microscope.

the particles to stick together a little. Yet there are air spaces between them. Moisture around each particle of soil provides water for plant roots, and the air spaces let the roots and soil bacteria get air.

Another important fact about the water in soil is the way it moves. Of course you know that gravity pulls rain water downward through the soil and also makes it run off the surface of sloping ground. Water can run rapidly downward through sandy soil. Through clay soil it moves very slowly. Through loam it can move at a medium rate.

The water is pulled downward in the soil until it comes to a layer of rock or soil through which it cannot pass. Since it can go no farther, it remains between the particles of soil. The soil that is filled with water between its particles is said to be *saturated* soil, and the top of the saturated soil is called the *water table*. When gravity has pulled the water as far down as it can, the thin film still remains around each tiny particle of soil.

Plant roots absorb water from the films around the soil particles. But, as you can readily see, the films touching

the roots are soon used up. What happens then? Can roots get some of the water that has sunk into the soil?

EXPERIMENT 63. *How Does Water Move toward Plant Roots?* (*a*) Put two saucers side by side and fill one of them about half full of colored water. Put one end of a dry lamp wick into the water and let the other end extend into the dry saucer. Watch for several days to see what happens. Be sure the half of the wick in the dry saucer is dry at the beginning of the experiment.

(*b*) Your teacher will put some very fine glass tubes of different diameters into some colored water. These tubes will be about ten inches long. Look closely at the tubes to see what happens. In which tube does the water rise the highest? In which does it stand the lowest? Make a statement about the diameters of the tubes and the height to which the water rose.

(*c*) Tie a cloth over the top of a lamp chimney. Turn the chimney upside down and pack it full of very fine (screened) loam or clay soil. Stand the chimney full of soil in a pan that contains about an inch of water. Does the water rise above its own level in the soil? How high is it at the end of a half-hour? Of twenty-four hours? Does it reach the top?

In the experiment you saw that water moved through the wick into the dry saucer. You also saw that water rose inside small glass tubes. And finally you saw water rise to the very top of a glass chimney full of soil. You make use of the same process every time you blot ink from a paper or dry your face with a towel. The process by which the water moves through small spaces in wicks, tubes, towels, blotting paper, and soil is called *capillary action.*

Now you can understand how water moves upward and sideways in the soil. The tiny spaces between particles act as the capillary tubes did in the experiment. Rain water that has gone down below the plant roots can move upward for a distance of three or four feet to the drier soil

FIG. 373. This farmer is cultivating the soil with a disc harrow and a drag. In addition to preparing the soil for planting, such breaking up of the top soil helps keep moisture in the soil.

around the plant roots. In the experiment you noticed that the water rose highest in the smallest tube and that it rose hardly any in the largest tube. The same thing is true of soil. The smaller the spaces are between the particles of soil, the higher the water will rise. In very large spaces it will rise hardly at all.

You have now learned that soil is best for farming when it is neither too wet nor too dry. Then each particle of soil is surrounded by a film of water, and air spaces are left between the particles. You have also learned that water can move upward and sideways by capillary action. The smaller the spaces between soil particles, the farther the water will move. Let us now see how farmers use these facts to keep their soil in good condition.

Self-Testing Exercises

1. Why is it important that the soil have just the right amount of water in it?

2. What is the difference between the way water is held in the soil in saturated soil and in moist soil?

3. How does capillary action provide water for plant roots?

FIG. 374. The Gunnison, Colorado, irrigation tunnel. This tunnel brings water from the Gunnison River, six miles away on the other side of the mountain. Two hundred thousand acres of land that was once desert have been turned into fine farms.

HOW DO FARMERS CONTROL THE AMOUNT OF MOISTURE IN THE SOIL? In many parts of the world man has found vast stretches of good soil that needs only water to make it grow wonderful crops. In India and Egypt, in China and Japan, in Canada and the United States much soil cannot be used because less than ten inches of rain falls on it each year. Near much of this land are great rivers with plenty of water. From primitive times until the present, men have tried to find ways of getting water from the streams to the soil.

Today in the United States more than 20,000,000 acres grow crops with water brought to them through *irrigation* ditches and tunnels. The best engineers of the country have helped the government and private companies to build dams and tunnels for controlling water and sending it to the thirsty soil. The great Elephant Butte irrigation dam across the Rio Grande River stores enough water to cover the whole state of New York one inch deep. From many such dams water runs through canals, tunnels, and ditches to farms where good crops are grown. Each farmer digs small ditches to carry water to his rows of plants. Running between the rows the water sinks into

FIG. 375. Irrigating celery on a farm in Venice County, Florida. Notice that the water is brought in pipes. (Ewing Galloway, N. Y.)

the soil and reaches the plant roots. Great stretches of desert lands have been changed into rich farming regions by irrigation.

In regions where the rainfall is between ten and twenty inches per year, crops can be grown without irrigation. However, the farmers must carefully save every bit of rain that falls. One plan they follow is called *dry farming*. In dry farming the top soil is kept loose and well broken up all the time. The large spaces in the loose upper soil keep the water from reaching the surface by capillary action, where it would evaporate rapidly. Thus most of the water in the soil is saved for the plants.

Another part of dry farming is carried out by letting each field lie idle, but cultivated, for one year out of every two or three. This allows every bit of rain to soak into the ground and prevents most of it from evaporating again. During the years when the land is idle, its store of water is being saved for the years when a crop is growing.

Almost all up-to-date farmers use some of the features of dry farming to save soil moisture during the dry periods of summer. They cultivate their fields of corn, potatoes, cotton, and other growing crops to keep the upper layer

of the soil broken up and loose. Thus they prevent the rise and loss of soil water.

In some parts of our country much valuable farm land is too wet for crops to grow well. For some reason the water cannot drain out of the soil, or it drains out so slowly that the farmers cannot plant their crops in time to grow during the warm season. On many farms open ditches are dug to allow the water to drain away quickly after a rain. However, experiments show that the best way to drain water from the soil of a farm is to bury tile drain pipes in the soil.

These tile pipes are in short pieces from three to six inches in diameter. They are made of fired clay, much as bricks are made. Long lines of pipe laid end to end are buried in the soil at depths of from eighteen inches to four feet. The lines of tile must have a gradual slope so that the water will run through them easily. The lines are usually spaced from fifty to one hundred feet apart, depending on the kind of soil to be drained. Water seeps from the soil into the pipes through the joints and runs rapidly through the smaller tiles until it reaches a large pipe line or a stream.

As you can see, laying tile drains is quite expensive. However, wet clay soils become much more fertile and can be cultivated much earlier in the spring when they are "tiled." Therefore the cost of the tile may be more than equalled by better crops, or totally unusable land may be made fit for use.

FIG. 376. Laying drainage tile

Self-Testing Exercises

1. How does breaking the surface of the ground keep moisture in the soil?
2. What is dry farming? Explain.
3. Make a list of the ways in which the amount of water in the soil is controlled. Mark with a star the ways used in your community.

Problems to Solve

1. Read in some Government Bulletin or reference book in order to learn more about tile drainage. List the advantages and disadvantages of this method of removing water from soils.
2. What are some of the disadvantages of using open ditches to drain water from soils. (See pages 142-158 for one disadvantage.)
3. Read in an encyclopedia or geography about dry farming. Find some places where this plan is used and learn what the principal crops are. Do the same for irrigation.

HOW IS SOIL KEPT FERTILE? Perhaps you have helped your father spread fertilizer on the lawn or garden. Probably you knew that the fertilizer helped the plants to grow better. In fact, your father may have said, "If we don't fertilize the lawn this spring, we won't have any grass left." What does fertilizer do to soil, and why do we have to fertilize our gardens and farms?

Many a farmer has carefully cultivated his soil, planted seeds, and had perfect weather for growing, only to have his crops grow poorly. The plants were small, their stems and leaves were a sickly yellow-green, and the farmer received very little profit for his work. Today in our country there are thousands of acres of worn-out soil—soil that will not grow strong, healthy food plants. How can soil become worn out, or infertile, after a few years of farming? You know that nature keeps soil fertile for thou-

FIG. 377A. This Coryell County, Texas, cotton field produced small, spindling plants with a poor yield of cotton, because the soil lacked the needed elements for plant growth. Now look at Figure 377B.

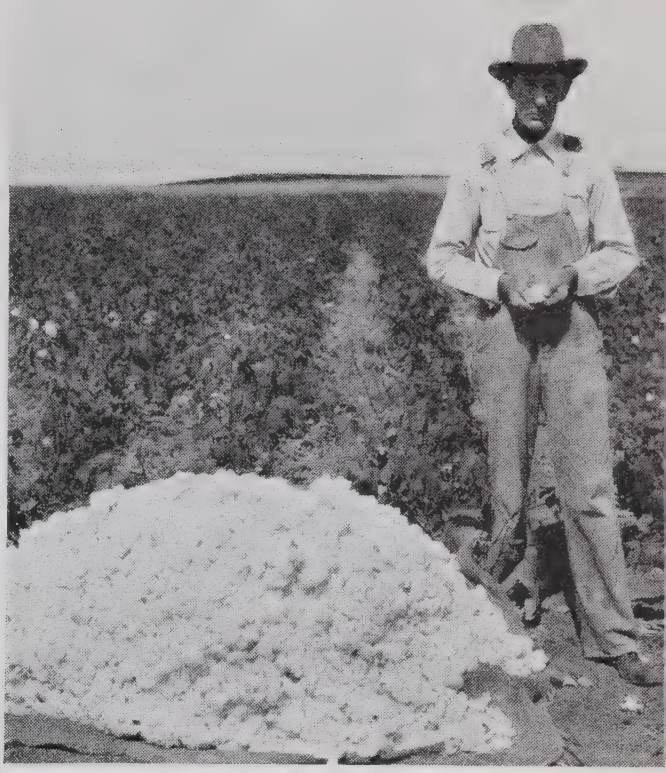


FIG. 377B. When the proper fertilizer was added to the soil, the plants grew taller and thicker, and a fine crop of cotton was gathered from the plants.

sands of years. Strong, healthy trees and other plants continue to grow on it without any care from man.

As you already know, there are certain kinds of chemicals in soils. Some of these chemical substances dissolve and are used by plants as they grow. At least ten elements are necessary to make crops grow well. Of course, these elements must be in the form of compounds that can dissolve and be used by the plant. In soil that is not used for farming, the plants die after a time, and their minerals are returned to the soil as they decay. In farming, however, the plants are usually gathered and taken away. Thus the valuable minerals they contain are lost to the soil.

Table 6 shows how much of certain important elements are taken from the soil each year by some common crops. You can easily see that removing these elements from the soil year after year would make the soil less fertile. An experiment done in England showed that when wheat was

Fig. 378. This picture shows how important certain minerals are to plant growth. In jars 2, 3, 4, and 5 the soil was the same, except that in jar 2 it lacked nitrogen, in jar 3, phosphorus, and in jar 4, potassium. In jar 5 all three minerals were present, and the plant grew tall and strong. Jars 6 and 7 show the growth of another kind of plant with and without nitrogen, the soil being the same in every other way.

planted in the same field for several years, the yield was decreased by one-third. Other experiments show even greater losses in soil fertility.

Table 6. Approximate Amounts of Important Minerals Taken from an Acre of Soil in a Single Year by Average Crops*

Crop	Pounds of Nitrogen	Pounds of Phosphorus	Pounds of Potassium	Pounds of Magnesium	Pounds of Calcium
Wheat	58	10	35	4	6.4
Corn	74	12	56	8	11.1
Soy-beans . .	108	15	48	....	28.2
Alfalfa hay . .	200	18	96	15	145.0
Cotton	102	18	59	....	....

*From *The Farm*, by Eugene Davenport. Macmillan, 1927.

Experiments have shown one reason why crops become poorer if the same kind of crop is planted year after year. The reason is that the same minerals are taken from the soil. If other crops are planted, different minerals may be taken from the soil. Some scientists believe that the roots of each kind of crop give off poisonous substances into the soil. When the same crop is planted year after year, these poisons accumulate and stop plant growth. If other crops

FIG. 379. On an experimental farm in Georgia this corn was grown to show the value of crop rotation. The corn at the left is growing in soil where corn was planted year after year. The tall, strong corn at the right is growing in soil that was used for other crops every two or three years.

are planted, the poisons drain away, and later on the soil becomes fit for use again.

When you remember how the soil is kept fertile under natural conditions, you can easily see one way in which farmers keep their soil fertile. They return to the soil as much as possible of the crops they raise. They "plow under" the corn stalks, cotton stalks, and straw left on the soil, instead of burning them. They scatter on their fields large amounts of manure from the farm animals, mixed with the straw used for "bedding." Sometimes farmers even plow under an entire crop of clover, soy-beans, or rye. In these ways large amounts of valuable chemicals and humus are returned to the soil.

Another way of keeping the soil fertile is by *crop rotation*. This is done by planting a different crop on a field each year. Wheat, oats, or other crops are alternated with *legumes*, such as clover, alfalfa, vetch, or soy-beans. As you learned earlier in your science study certain kinds of bacteria in the soil grow on the roots of legumes. These bacteria take pure nitrogen from the air and manufacture nitrogen compounds that can dissolve in the soil water and be used by plants.

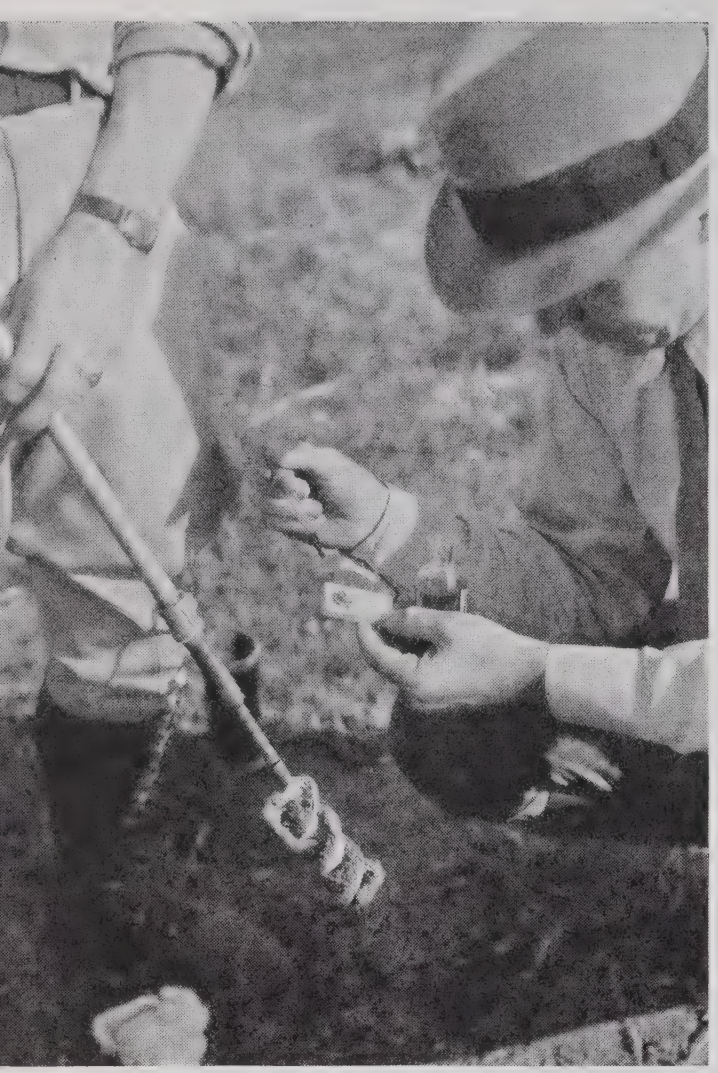


Fig. 380. Scientists testing soil to find what it needs to make plants grow well. They have used a drill to get a sample from some distance below the top soil.

When legumes are cut, the roots are left in the ground. As they decay, the nitrogen compounds in them are added to the soil. This, of course, enriches the soil. This plan also avoids any bad effects caused by planting the same crop year after year.

Experiments made over long periods of time show that crop yields have been increased by as much as fifty per cent by means of crop rotation. An example of a crop rotation worked out by one experimenter is:

First year: Corn or cotton followed by clover in the fall.

Second year: Wheat, barley, or oats followed by clover or grass in the fall.

Third Year: Repetition of first year's crops, etc.

Another plan of crop rotation that is very common in the central United States is as follows: *First year:* Corn. *Second year:* Wheat or oats. *Third year:* Clover or soybeans. *Fourth year:* Repetition of first year's crops, etc.

The third common way of increasing the fertility of the soil is by adding *commercial fertilizers.* When a farmer thinks his soil needs fertilizer, his problem is to find out what elements the soil needs. One way to do this is to

send samples of his soil to the agricultural experiment station of his state. The scientists there will test the samples carefully and tell the farmer what the soil needs. However, rather simple tests have been worked out so that the farmer can buy a soil-testing "kit" and test his soil himself (Figure 380).

Sometimes careful observation of the appearance of growing crops tells the farmer or the agricultural expert what is lacking in the soil. When he knows what elements his soil needs most, the kind of fertilizer that gives best results on his soil, and the kind of crop he wishes to grow, the farmer can select his fertilizer intelligently.

Only three elements are likely to be lacking in the soil. These three are nitrogen, phosphorus, and potassium. In choosing his fertilizers, the farmer looks at tables like Table 7. He then buys the fertilizers that give the elements his soil needs and mixes them together before putting them on the land. Or he may buy fertilizer that is mixed ready to use and has the right amounts of the different elements in it.

Table 7. Average Composition of Common Fertilizers*

Kind of Fertilizer	Per Cent of Elements (in the form of Compounds)			Rate at Which Fertilizer Becomes Usable by Plants
	Phosphorus (as Phosphoric Acid)	Nitrogen	Potassium (Potash)	
Raw rock phosphate	28.0	....	....	Very slowly
Ground bone	22.0	3.5	....	Very slowly
Nitrate of soda	....	16.0	....	Very quickly
Dried blood	....	14.0	....	Medium
Tankage	7.0	7.5	....	Slowly
Dried fish	6.0	9.0	....	Slowly
Cottonseed meal	2.8	6.2	2.5	Slowly
Sulphate of potash	....	....	48.0	Quickly
Fresh ashes	1.9	....	5.5	Medium

*Condensed and simplified from *Crop Production*, by H. D. Hughes and E. R. Henson. Macmillan, 1930, p. 193.

FIG. 381. These men are spreading ground-up limestone on the soil of an Indiana farm to keep the soil from becoming acid, or sour.

Sometimes crops do not grow well on soil because the soil has become *sour* or *acid*. When this difficulty is suspected, special tests can be made to make sure. One way is to press a lump of moist soil against a piece of blue *litmus-paper*. If the litmus-paper turns pink, the soil is sour. This condition can usually be improved by good drainage and by using lime or ground limestone. Good drainage carries away the acids that are always being formed in the soil by plant roots. The lime causes a chemical change in the acids, turning them into substances that are harmless to plants.

The soil of our country is so important that large sums of money are spent each year to learn the best ways of taking care of it. At the present time the United States government is carrying on a tremendous program to prevent the loss of fertile soil from our farms. The results of careful study and hundreds of experiments are published in free bulletins and carried to farmers all over the country by speakers sent out from the experiment stations.

Self-Testing Exercises

1. Give two reasons why a field may become less fertile when the same crop is grown on it year after year.

2. Why do good farmers "plow under" much plant material and manure?

FIG. 382. To get phosphorus for fertilizer, phosphate rock is dug up and crushed. Florida is the only state in our country where phosphate rock is found.

3. What is crop rotation? Give an example. Why is crop rotation important in farming?

4. Why are legumes especially valuable to farmers?

5. How does a careful and scientific farmer decide what fertilizer to use?

6. How can acid soil be made more fertile?

Problems to Solve

1. Find in reference books plans of crop rotation that are different from the plans described in this book. Make a report on them to your class.

2. Find out what legumes are grown on the farms in or near your community.

3. Get some samples of commercial fertilizers and find out what their analysis shows, that is, the amounts of the three important elements in the fertilizer.

4. Plan and carry out some experiments to see if the fertilizers you get will make plants grow better.

5. Obtain some blue litmus-paper from a school laboratory or from a drug-store. Then test samples of moist soil from your locality to see if any are acid.

6. Write to your state experiment station for bulletins on soil cultivation, drainage, and the use of fertilizers and lime. Report to your class any interesting new ideas you get from the bulletins.

FIG. 383. This boy is using a hand cultivator to keep the garden clear of weeds and to loosen the soil around the plants.

Problem 2:

HOW DOES MAN PROTECT HIS PLANTS AND ANIMALS FROM THEIR NATURAL ENEMIES?

HOW DO FARMERS TRY TO KEEP WEEDS OUT OF THEIR CROPS? Did you ever have the job of keeping the weeds out of the garden as a part of your work about the home? You got rid of the weeds as thoroughly as you could; then you forgot all about them. Before long your mother asked if you had weeded the garden recently. You looked at the garden and were surprised to find that the weeds had grown again and that there were almost as many as when you first started. They seemed to grow as if by magic.

The farmer's problem is even greater than yours. He has to fight the weeds in fields that cover many acres. As you have learned, there is a constant competition between plants for light, moisture, and minerals. Weeds fight our food plants for light, water, and minerals in the soil. Weeds are said to reduce the yield of corn in the United States by ten per cent. What the farmer

FIG. 384. Crop rotation also helps in the fight against weeds. Crops that are planted thinly, like corn, give weeds a chance to grow. But when they are followed by crops that are thickly grown, such as cowpeas or alfalfa, many weeds are smothered. You can easily see how this thick growth of alfalfa would keep weeds from growing in this orchard, in addition to adding valuable nitrogen to the soil.

needs to do, then, is to keep the weeds from growing and competing with his crops. Some weeds and weed seeds mixed with grain and hay also reduce the price the farmer can get for these crops.

Strange to say, however, farmers often plant weed seeds unknowingly. These seeds get mixed with the seeds of farm crops and are planted. Small grain seeds, such as wheat or oats, often contain seeds of wild onion, ragweed, quack grass, and other weeds. This can be avoided to some extent by buying seeds from reliable companies. Such companies usually label their bags of seeds to tell the percentage of weed seeds. For example, a purity tag, reading 99.9 per cent, would mean that one thousand seeds would contain only one weed seed.

The farmer starts his fight against weeds with a handicap. The soil has many weed seeds in it from the previous year. These are ready to come up as soon as the spring rains and warm weather come. Thorough cultivation with harrows, special types of cultivators, plows, and hoes is a good way of fighting weeds. This cultivation must be

kept up at regular intervals so that the weeds will not have a chance to mature and produce seeds. Using such methods year after year helps to keep the number of weeds greatly reduced.

Many other ways of destroying weeds have been tried. Pasturing land with hogs, cattle, sheep, or goats helps to destroy them. Some chemicals, such as salt, oil, and iron sulphate, have been used. Machines that burn the weeds have been invented. Some kinds of weeds, such as Canada thistle and quack grass, are so difficult to destroy that special methods have to be used to keep them under control. (See page 449.)

FIG. 385. There are many kinds of thistles, and they are all serious weed pests.

Self-Testing Exercises

1. Make a list of all the reasons you can think of as to why farmers should keep weeds out of their crops.

2. What is meant by "purity of seeds"?

3. Without looking at your book, make a list of ways in which farmers try to control weeds. After each item in your list, write one sentence to explain how that method of destroying weeds works. Put a star in front of the methods that you know are used in your community.

Problems to Solve

1. What seeds or crops raised in your community are most liable to contain weed seeds?

2. Suppose the officials of your county or city wish to set a time for mowing weeds along the roadsides. What would be your recommendation as to the most favorable time?

HOW CAN WE KEEP OUR INSECT ENEMIES UNDER CONTROL? Suppose the farmers of our country were to receive $2,000,000,000 more each year than they make now. How much better off they would be! If we could get rid of insects that damage crops, farmers would earn that much more money; for insects cause that amount of loss to farmers each year. Certainly you do not have to be told anything more to show you that controlling insect pests is one of the biggest problems of farmers. How can scientists and farmers go about it intelligently?

FIG. 386. Grasshoppers are very destructive insects. This corn plant has been chewed up by grasshoppers.

One of the first things *entomologists* (people who study insects) try to find out about insects is their life histories. You learned in Unit 10 that insects go through different stages as they mature. Entomologists must know what the insects are like in each of these stages, where they live during these periods, and what they eat. Sometimes it is the larva that does the damage; sometimes it is the adult insect. When these things are known, methods of fighting the insects can be worked out. Some examples will make this clear to you.

One destructive insect is the common *stalk borer*. The larvae (caterpillars) of the stalk borer injure corn, wheat, beans, potatoes, and other vegetables by boring into the stems of the plants and feeding there. Controlling them is difficult because the insects are inside the plant stalks during the period when it would be easiest to kill them.

Entomologists have learned the life history of the stalk borer. The eggs are laid on the stems of wild plants and stay there all winter. They hatch in May or June, and the larvae bore into stems of the wild plants. Later they migrate to cultivated crops and bore into the stems of those plants. In August these insects turn into pupae in their homes in the plant stems. About three weeks later they hatch into adults. Then they come out and lay their eggs on the stems of wild plants. By knowing their life histories, entomologists have found the best way to control these pests. Burning wild plants in late autumn and early spring destroys the eggs and greatly reduces the numbers of the insects.

FIG. 387. Life history of the stalk borer—adult, eggs, pupa, and larva

Southern farmers have learned that cotton *boll weevils* do not grow into larvae until midsummer, when the weather is very warm. This is the stage when these insects do the most harm to cotton crops. If the farmers plant their cotton early so that it matures early, many of the cotton bolls will be too mature for the larvae to damage them. Just the opposite is true in other cases. Wheat will avoid much injury from the *Hessian fly* if it is

FIG. 388. Burning over a field to destroy corn borers

sown late enough. The adult flies develop in the fall and die within a week or ten days. If the wheat is not planted until after the flies die, it will escape serious injury from these pests.

Thorough cultivation of the soil at all times is a good way of fighting insects. In preparing the soil for planting many insects are killed. Others are killed during cultivation while the crops are growing. Still others are exposed to unfavorable weather and to birds as the soil is turned over in plowing.

Crop rotation helps control insects. For example, certain kinds of *wireworm* larvae live in the ground during the winter. In the summer they mature and attack the roots of corn and other grain crops. Planting corn on the same plot of ground only once in every three or four years limits their food supply. Most of the insects then die, and a new supply is not hatched out to damage the corn plants. *Wheat-straw worms*, certain kinds of "grub worms," and other harmful insects may be controlled in a similar manner. Insects that damage plants are sometimes poisoned with chemicals. Such poisons as arsenate of lead, Paris green, and lime-sulphur mixtures are used.

FIG. 389. Boll weevils on a cotton boll

FIG. 390. The chemicals used to poison insects are mixed with water, kerosene, or other liquids and sprayed on the plants, or they are dusted on them dry. Sometimes airplanes are used to spread dust poison over large fields of plants.

Were you ever stopped at some state border and asked if you had any plants in the car? In many states there are quarantine laws against taking plants into the state unless they have been thoroughly inspected for insect pests and plant diseases. Such a plan helps to keep insects and plant diseases out of states that are free of them.

Did you ever see sticky bands of paper or cotton batting fastened around the trunks of trees? If you examined these bands closely enough, you may have found many insects sticking to them. One way of fighting spring and fall *cankerworms* that damage apple trees is by means of sticky bands. These bands keep the worms from getting into the trees and thus damaging the apple crop.

Birds are of tremendous importance in helping control insects. Flycatchers, woodpeckers, swallows, orioles, cuckoos, warblers, and many other birds depend upon insects for a large part of their food supply. Their ability to fly makes birds especially useful to the farmer. Swallows and flycatchers catch insects in the air while they are flying. Robins get their insect food off the ground, while nuthatches and brown creepers catch insects on the bark of trees. Still other kinds of birds, warblers and orioles, for example, catch leaf-eating insects.

It has been estimated that 100 bluebirds destroy 760,000 insects in eight months. Of this number there would be 70,000 moths and caterpillars (many of them *cutworms* that gnaw off the stems of young plants), 12,000 *leaf hoppers* (that suck the juices of plants), 10,000 *curculios* (small grubs that make plums and cherries fall before they are ripe), and 65,000 crickets, locusts, and caterpillars.

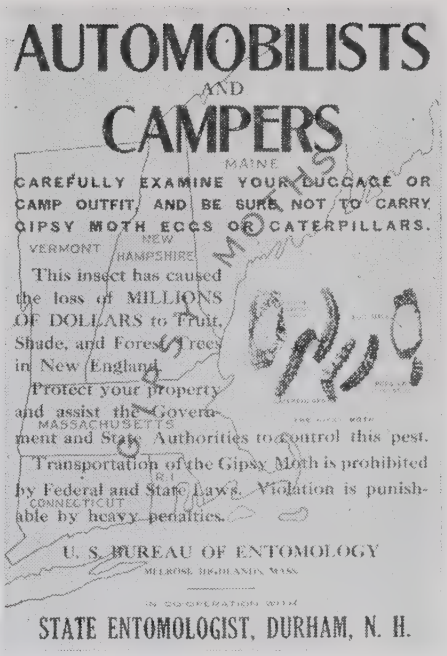

AUTOMOBILISTS
AND
CAMPERS
MAINE
CAREFULLY EXAMINE YOUR LUGGAGE OR CAMP OUTFIT, AND BE SURE NOT TO CARRY GIPSY MOTH EGGS OR CATERPILLARS.
VERMONT
NEW HAMPSHIRE
This insect has caused the loss of MILLIONS OF DOLLARS to Fruit, Shade, and Forest Trees in New England.
Protect your property and assist the Government and State Authorities to control this pest.
MASSACHUSETTS
Transportation of the Gipsy Moth is prohibited by Federal and State Laws. Violation is punishable by heavy penalties.
R.I.
CONNECTICUT
U. S. BUREAU OF ENTOMOLOGY
MELROSE HIGHLANDS, MASS.
IN CO-OPERATION WITH
STATE ENTOMOLOGIST, DURHAM, N. H.

FIG. 391. The *gypsy moth* is another destructive insect.

Scientists say that the birds in one state alone—the state of Massachusetts—destroy 21,000 bushels of insects a day (each bushel containing about 120,000 insects) during the five months of late spring, summer, and early fall.

FIG. 392. A band of sticky paper to keep larvae from getting up to the leaves of the tree

The amount of damage that could be done by these insects is tremendous, and if they were allowed to go on living and reproducing, millions more would be added to their numbers. It has been said that if it were not for the birds, in ten years man would be unable to keep alive on the earth; the enormous numbers of injurious insects would destroy every green plant.

FIG. 393. The Australian ladybird beetle: (*a*) larvae feeding on cottony-cushion scale, (*b*) pupa, (*c*) adult beetle, (*d*) scale on a twig with beetles, larvae, and eggs

For these reasons birds should be protected, and they should be encouraged to nest in orchards and other favorable places. Putting up nesting boxes, providing a supply of water, and protecting them from cats and other enemies are the more important ways in which the farmer and all of us can help birds. In turn, the birds will help us by eating insects that injure the plants we need for food.

Sometimes insects are used to fight other insects that damage crops. These helpful creatures are known as *predaceous insects* because they prey upon other insects. A certain kind of insect that is covered by cotton-like pads once caused serious damage to the orange and lemon crops in California. This insect, called the *cottony-cushion scale* insect (Figure 393), damages orange and lemon trees by sucking the sap from the bark.

Scientists learned that the Australian ladybird beetle feeds on these scale insects. Therefore Australian ladybird beetles were imported into our country in large numbers. These beetles have destroyed so many of the scale insects that they no longer seriously damage orange and lemon crops. Other kinds of ladybird beetles are used to fight insects that injure our melon crops.

The European ground beetle has been imported into the United States to check the damage done by gypsy moths. Gypsy moths have ruined millions of forest, fruit, and shade trees by eating the leaves from the trees.

Self-Testing Exercises

1. Write a paragraph telling in your own words why the life histories of insects should be known before an attempt is made to control these pests. If you can, give an example (other than those in the text) to illustrate your discussion.

2. List the different ways of fighting harmful insects that are mentioned in the text. Put a star in front of the methods you have seen tried.

3. What are predaceous insects? Name those that you are familiar with.

Problems to Solve

1. Does your state have plant quarantine laws? Try to find what they are.

2. Make a list of insect-pest problems that need to be solved for your community.

3. Try to collect the eggs, larvae, pupae, and adults of some common kind of insect pest. Label and mount these on cotton under glass for study in your class.

4. What birds in your community are helpful in fighting insects? What insects?

5. Collect pictures and make a booklet of birds in your community that destroy harmful insects. Give a description of each bird and tell how it is helpful.

FIG. 394. A cutworm with a tomato stem that it has cut almost off. The cutworm attacks the stem of the plant below the surface of the soil.

HOW DOES MAN PROTECT HIS PLANTS FROM DISEASES? Did you ever see a field of corn in which some of the ears looked like the one in Figure 395? This corn had a disease known as *corn smut*. You have learned that plants and animals are alike in many ways. Another way in which they are alike is that they both have diseases. The greatest amount of injury is done to plants by disease caused by non-green plants, such as fungi and bacteria. They cannot make their own food; so they live on green plants and use the green plants for food. In this way they destroy or seriously injure the green plant. Many of these fungi and bacteria produce spores that scatter the diseases from one plant to another.

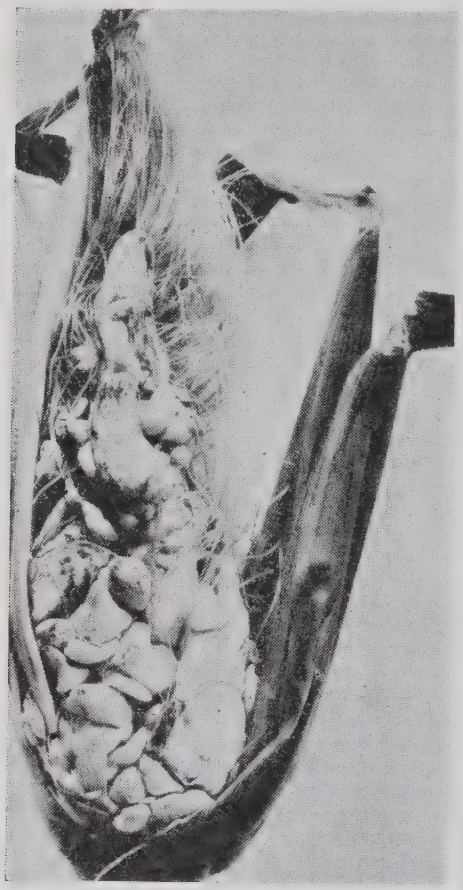


FIG. 395. A corn ear ruined by corn smut

Several methods of controlling plant diseases are used. One method is to grow plants that can resist fungous diseases. For example, it has been found by experimentation that certain varieties of potatoes resist the attacks of fungi better than other varieties of potatoes. This is also true for different varieties of many other plants. If farmers select and grow the kinds of plants that the fungi cannot injure, their plants will stand a better chance of producing good crops.

Certain kinds of organisms that cause plant diseases spend part of their lives on farm crops and part of their

lives on other plants. *Wheat rust*, which attacks the stems of wheat and destroys the plant, is a good example of this relationship. The rust first starts its growth on barberry bushes in the spring. Spores are produced, which are scattered by the wind, and fall on young wheat plants. Here the spore starts growth, and the mycelium enters the plant tissues, destroys the chlorophyll, and breaks open the stem of the plant. New spores are produced, and these fall on barberry bushes, where they start growth in the following spring. By destroying the barberry bushes, the spread of the disease is controlled, because the growth of the spores on the barberry bush is usually a necessary part of the life cycle. The parasite that causes *crown rust* of oats spends part of its life on oats and part of its life on buckthorn, a wild plant. When the buckthorn plants are destroyed, the disease-causing parasites cannot mature and produce crown rust to attack the oat crop.

FIG. 396. Apples ruined by apple scab, a fungous disease

Sometimes certain disease-producing organisms live in the soil. For example, as soon as a crop of potatoes is planted, *potato scab* organisms may attack it. Mixing chemicals with the soil helps kill these organisms. From 300 to 600 pounds of sulphur per acre has been used in controlling this disease. In other cases, where small amounts of soil are to be used, the soil is heated to kill any germs that are in it. Tobacco-raisers burn great piles of tree branches to heat the soil where they are going to plant tobacco seed. This kills the fungi that will injure the young plants.

FIG. 397. *Brown-rot*, a serious fungous disease of peach, plum, and cherry trees, causes cankers on the stems and dries up the fruit.

Another method of fighting plant disease is treating the seeds with chemicals before they are planted. These chemicals kill the disease-causing spores or other organisms that may be sticking to the seeds. Small amounts of powdered chemicals thoroughly mixed with wheat, oats, and barley have been found to be a good way to control some smut diseases in these plants. Different kinds of copper and mercury compounds are also used to treat seeds for certain diseases.

Crop rotation is helpful in fighting plant diseases just as it is in fighting insect enemies of plants. When crops other than cotton are planted for more than two years in fields where *cotton wilt* has been, the damage done by this disease is greatly reduced. When cotton is not grown, the disease germs cannot get food; therefore they die. The same is true of potato scab. A few diseases are so serious and hard to control that diseased plants must be removed and destroyed as fast as they appear.

Self-Testing Exercises

1. Make a list of ways of protecting plants from disease. Opposite each item in your list, write a sentence telling how the method works.

2. How does the use of disease-resistant varieties of plants help control plant disease?

3. How does crop rotation help farmers in their fight against plant diseases?

Problems to Solve

1. Make a list of common plant diseases that occur in your community. Find what methods are used to protect plants from each of these diseases. If possible, bring to class specimens of plants that have these diseases. Burn the plants when you are through with them.

2. In a good reference book find out more about how destroying barberry bushes helps control black stem rust of wheat.

HOW DOES MAN PROTECT HIS ANIMALS FROM DISEASES AND INSECT ENEMIES? Animals, as well as human beings and plants, have diseases, and in many cases these diseases can be cured or prevented. You probably remember when you were vaccinated against smallpox. Animals, too, may be vaccinated and treated for diseases. If you have forgotten how we protect our bodies against diseases, read Unit 9 again. It will help you to understand better how *veterinarians* (animal doctors) protect animals.

Do you know that a disease known as *blackleg* kills over $6,000,000 worth of cattle every year in the United States? The great loss from this disease can be prevented by vaccination. From three to six million hogs in the United States die each year from *cholera*. Think how much more money the farmers would have if these hogs could be saved. And farmers can save these hogs, for hog cholera, like blackleg, can be prevented by vaccination. There are two kinds of vaccination against hog cholera, single and double.

FIG. 399. Inoculating a hog with hog-cholera serum

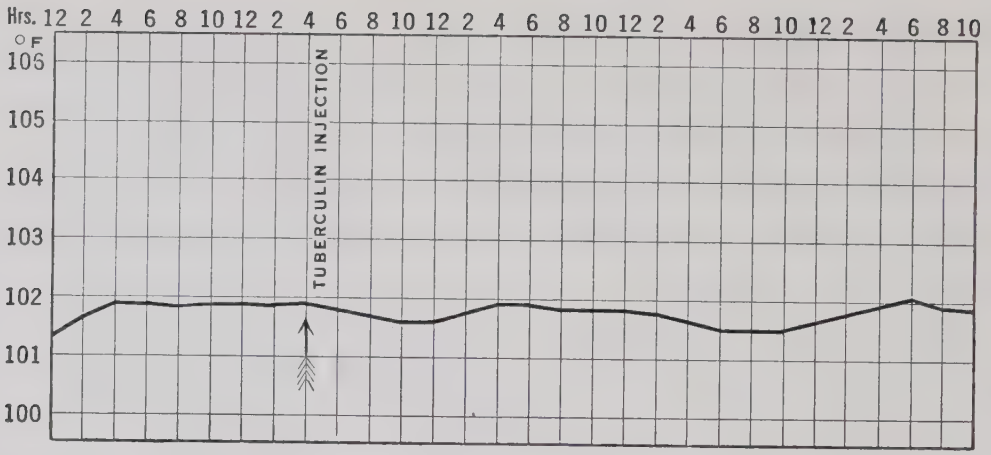


FIG. 399A. The temperature of a healthy cow shows very little change after the cow is given the tuberculin injection. Now study the chart in Figure 399B to see what the test shows.

The single vaccination with hog-cholera serum is used when the disease is already in the herd. Serum, you recall, is the clear liquid from the blood of animals that have had the disease. It contains antibodies that fight the cholera germs (see page 424). Single vaccination protects hogs for about three or four months. Then they can take the disease. In double vaccination both serum and *virus* are injected, but in different parts of the body. Virus is serum that has hog-cholera germs in it. When the germs in the virus get into the hog's blood, the hog's body makes antibodies to fight the germs. The serum quickly kills the cholera germs, so that the hog does not get cholera. The antibodies made by the hog's own body stay in the blood for life, and the hog is immune to cholera.

Another widespread cattle disease is *tuberculosis*. The great danger of this disease is that human beings can take it by drinking milk or eating meat from infected cows. One of the most serious fights against animal disease today is the fight against tuberculosis in cattle. Unfortunately, no treatment for this disease has been found. The sick animals must be destroyed. The *tuberculin test*

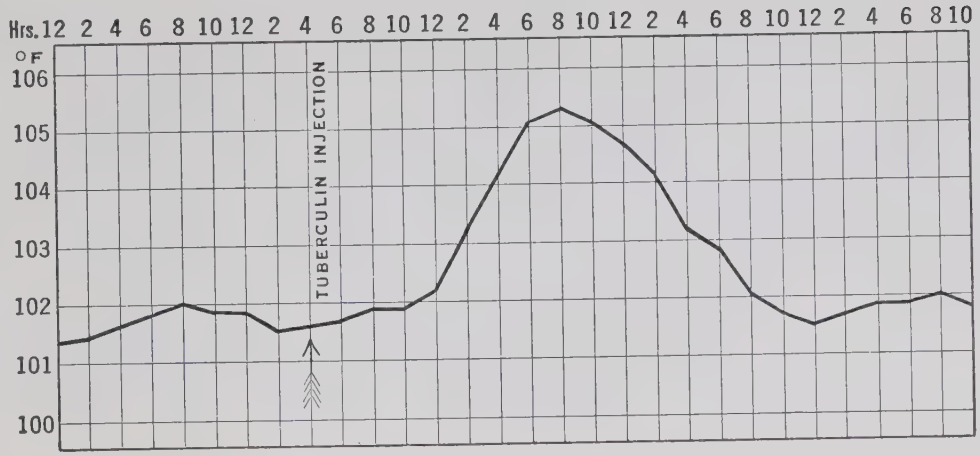


FIG. 399B. The temperature of a cow that has tuberculosis will rise a number of degrees within a few hours after the injection.

is used to tell whether apparently healthy cattle have this disease (Figures 399A and 399B).

Of course, there are many other kinds of animal diseases. But these examples show you how farmers can use scientific knowledge to protect their animals against disease.

Animal parasites often injure livestock and sometimes even cause death. *Ticks* get into the hairy covering of cattle and sheep. In addition to irritating and weakening the animals, the ticks in some regions of our country carry germs of serious diseases. To get rid of ticks the animals are made to swim through a bath of insecticide that kills the pests, but does not injure the animals.

Other examples of parasites are chicken *mites* and lice. Lice live in the feathers of chickens and irritate these birds by biting their skin. Dusting sodium fluoride through the feathers is a good way of preventing or destroying chicken lice. Mites stay in cracks between boards of the chicken houses, on roosting poles, and in other hiding-places during the day. At night they crawl on the chickens and suck their blood. Cleaning the chicken house thoroughly with a strong insecticide and whitewashing it to fill the hiding-place of mites usually gets rid of these pests.

FIG. 400. These sheep are being made to swim through a trench full of a liquid insecticide. (Ewing Galloway, N. Y.)

Someone has said that the best way to treat a disease is to prevent it. Animals are kept free from disease in much the same way that people are kept from becoming ill. One of the first things that can be done is to keep the living quarters of animals clean. Another way is to keep sick animals separated from the others as soon as they show signs of disease, that is, to quarantine them. Still another preventive measure is to quarantine for several weeks new animals that are bought. Any disease that they may have will probably develop during this time. Then, if they are free from disease, they can be turned in with the other livestock.

Self-Testing Exercises

1. What preventive measures have you seen used to help keep animals free from disease?
2. What is the difference between serum and virus? When is each used?
3. Tell in your own words how chickens are protected against (*a*) mites, (*b*) lice.

Problems to Solve

1. If there is a veterinarian in your community, visit him and find what animal diseases of your locality are the most serious and how they are treated.
2. Find how dairymen try to provide milk that is free from tuberculosis and other germs. Report to your class.

FIG. 401. This farmer is proud of his *ton-litter* of pigs. A ton-litter is a litter that weighs, in all, 2000 pounds or more 180 days after they are born. You may be sure that this farmer had to know how to feed the pigs in order to make them grow as they did.

Problem 3:

HOW DOES MAN SELECT FOOD FOR HIS ANIMALS?

IF YOUR school has a cafeteria, the person in charge plans the foods carefully to meet the needs of growing boys and girls. There must be foods to provide proteins, fats, carbohydrates, minerals, and vitamins. You need the proper amounts of these different food substances to make you grow and to give you energy to do your work. In other words, you need a balanced diet. In addition, the foods in a school cafeteria must be those that boys and girls like, and the cost must be reasonable.

In your earlier science work you have studied why we need to eat different kinds of foods. If you need to refresh your mind about the different kinds of foods, read about them in Unit 10 of Book One before you study this problem. Also review Unit 8 of this book.

However, this problem is not about the food of boys and girls, but about the food of farm animals. Does it seem strange to you to speak of planning a proper diet, or ration, for farm animals? It may seem strange, but successful farmers choose food for their animals with great

care. To grow properly, the animals must have the same kinds of materials in their food that you need in your food: proteins, carbohydrates, fats, minerals, and vitamins.

HOW IS THE PROPER FOOD SELECTED FOR DAIRY CATTLE? Let us first study about feeding the cows that provide us with our milk. When you see the problems that need to be solved to feed dairy cows properly, you can understand the problems that are connected with the feeding of any animal.

FIG. 402. Grinding and weighing feed for livestock on an experimental farm in Wisconsin

If you were a farmer and had a herd of dairy cows, naturally you would be interested in making as much money as you could. If you were an up-to-date farmer, you would get some of the bulletins on the feeding of dairy cows, published by the United States Department of Agriculture and by the state experiment stations. In these bulletins you would find all the information you would need to feed your cattle properly. This information has been obtained by experimenting for many years with thousands of cattle.

A cow is like all other living things in that she must have food to supply her needs. Inside the body of the cow many activities are constantly going on. Food is being digested, the muscles are moving, heat is being produced to keep up the body temperature, and new tissues are being manufactured to replace those that are worn out. The materials for the production of new tissue and for carrying on bodily activities must be provided; otherwise, the cow will lose in weight.

By careful experiments the amount of food needed to keep the body of a cow in good condition has been determined. By consulting a chart the farmer can find how much food a cow of a certain weight needs to keep her body going. In addition, the cow must have the food necessary to make the milk. For this, too, the farmer can consult a chart in an experimental-station bulletin. So, in feeding a cow it is necessary to provide food for three purposes: (1) for building new tissues, (2) as a source of energy for body activities, and (3) to provide materials for the production of milk.

When the farmer has found how much carbohydrates, fats, and proteins each animal needs, he can select and mix foods that will give the right amounts. Here again the farmer goes to charts in his bulletins. There he finds the results of chemists' analyses of various foods. The composition of a few common foods is given in Table 8.

TABLE 8. CHEMICAL COMPOSITION OF COMMON ANIMAL FOODS

100 Pounds of	Dry Matter	Protein	Carbohydrates and Fat	Nutritive Ratio
Alfalfa hay . . .	91.6	11.0	42.3	1:3.8
Clover hay . . .	84.7	6.8	39.6	1:4.7
Corn grain . . .	89.1	7.9	76.4	1:9.7
Corn silage . . .	20.9	.9	12.9	1:14.3
Linseed meal . .	90.8	29.3	48.5	1:1.7
Oats, grain . . .	89.0	9.2	56.8	1:6.2

You can see from this table that foods differ greatly in their composition. The first column, "Dry Matter," shows the per cent of food material after the water has been taken out. For example, 8.4 per cent of alfalfa hay is water, and 91.6 per cent is dry matter. In the last column the *nutritive ratio* shows the ratio between the digestible proteins and the carbohydrates and fats combined. A

FIG. 403. The rations for these cows on an Indiana farm are carefully weighed out at each feeding time, and records are kept of the kinds and amounts of feed.

nutritive ratio of 1:3.8 means that there are 3.8 times as much carbohydrates and fats as there are proteins. This ratio is figured out because it makes it easier to tell how to put the foods together properly to make a balanced ration for the animal.

The experimenters at the agricultural stations in different parts of the country get all of the information they can concerning all the food needs of animals. Then they make up many sample menus and feed different groups of cattle on each diet. They keep a careful record of the weight of the animal when the experiment started, changes in weight as the experiment progresses, and the weight of the milk produced. Hundreds of such experiments have been carried on. As a result, it is possible for the experiment stations to tell a farmer just what kind of menu to provide for his cows under all sorts of conditions.

WHAT PRINCIPLES SHOULD BE FOLLOWED IN FEEDING ANIMALS? Now that you have seen the problems that must be solved to feed dairy cattle successfully, you can think about the principles that must be followed in

feeding all animals. First of all, we must feed the animal the kind and proper proportion of the food substances that are found in its body. Table 9 shows that these food needs vary with different animals.

TABLE 9. SUBSTANCES IN LIVE ANIMAL BODIES

KIND OF ANIMAL	PER CENT OF SUBSTANCE			
	Protein	Fats	Mineral	Water
Well-fed hogs	15.0	24.2	2.9	57.9
Well-fed sheep	17.4	15.5	3.9	63.2
Fat calves	16.5	14.1	4.8	64.6
Grown steers well fed	19.2	8.7	5.9	66.2

We must feed the animal the kind of food that it can eat and digest. For example, garbage is not fed to horses, or timothy hay to hogs. Second, the animal must have the proper combination and amount of *roughage* (bulky foods that help make the intestines work well) and concentrated food to keep the animal healthy. Third, the food must provide for the manufacture of new tissue and produce the energy needed by the animal.

Fourth, the animals' food must furnish the proper materials to make the product that we need from the animal. In the case of milk cows, this product is milk. In the case of sheep, the product may be meat or wool. In the case of chickens, the product may be eggs or meat. When we are fattening animals for food, proper food must be supplied to make the additional flesh. Finally, we must consider the cost of food, and select the kinds that will secure the results with the least possible cost.

Self-testing Exercises

1. Do you think that it is correct to say that selecting foods for farm animals is based upon the same principles as selecting food for people? Give reasons for your answer.

FIG. 404. If you have ever traveled in the country, you have seen tall cylinder-shaped buildings near barns. They are silos for storing livestock feed. In this picture the men are cutting corn stalks into small pieces and storing them for winter feed. The tractor runs the cutter and the blower that blows the corn up into the silo. Many kinds of feed, such as alfalfa, soy-beans, and cowpeas, are stored in silos.

2. Make a list of the different things that must be known before one can feed dairy cattle the proper food. Explain why each thing must be known.

3. Why is experimentation necessary in learning how to feed animals?

4. How would you find what kinds of food your chickens would need?

Problems to Solve

1. Visit a farm and find out how the farmer decides what to feed his animals. Compare what he tells you with the principles you have just studied.

2. If possible, visit a dairy farm to find (1) how the milk is kept clean, (2) how the rations for the cows are planned, and (3) how the milk is tested.

3. Make a report on the kinds of food fed to different farm animals. Explain, if you can, why different kinds of food are fed to different animals.

4. If you have a pet animal, especially if you got it when it was young, tell how and what you fed it.

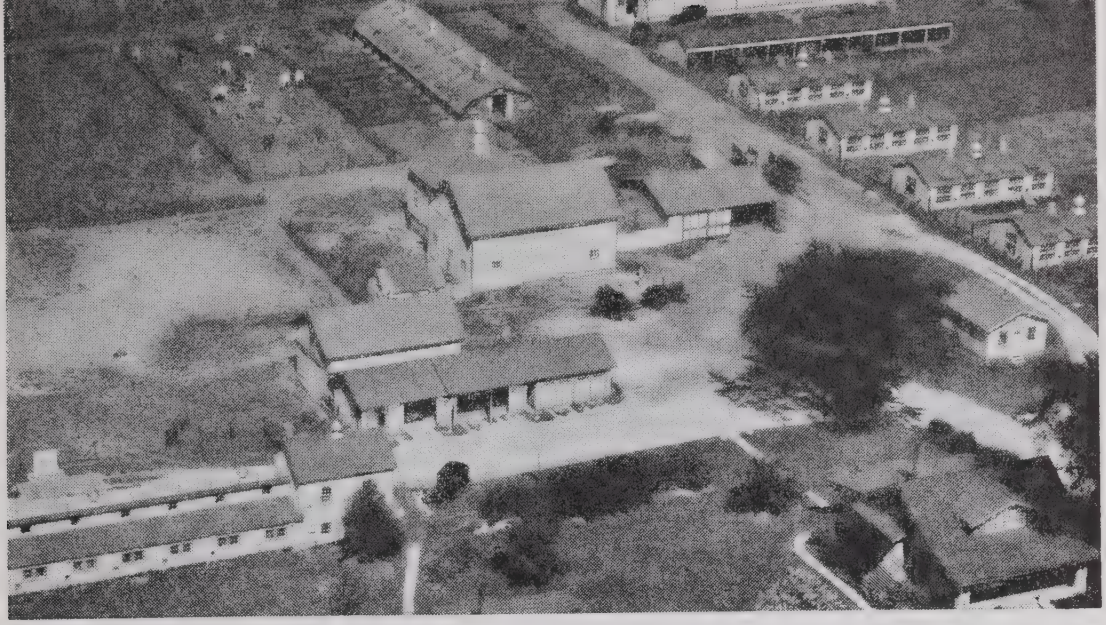


FIG. 405. An airplane view of a very fine set of farm buildings in Wisconsin. Study it carefully to note what kinds of buildings there are and how they are arranged.

Problem 4:

HOW DOES MAN PROVIDE PROPER HOUSING FOR HIS ANIMALS AND PLANTS?

HOW WOULD you like to live in a dark, damp, cold house? Do you think that you would be happy in such surroundings or that you would grow to be strong and healthy? While pigs, cows, and chickens are not human beings, they enjoy a comfortable place to live. Aside from the fact that the animals we raise should be comfortable, we find that it pays to keep them comfortable and contented. They eat more, grow faster, are healthier, and thus bring a higher price. Chickens will produce more eggs, and cows will produce more milk if their living quarters are properly designed.

Certain problems must be solved in planning modern farm buildings. How to provide protection from the weather, how to secure ventilation and light, and how to provide proper sanitary conditions are among the most important problems that must be solved. Of course, it will be impossible for us to study all kinds of farm buildings. Here you will study a few kinds of buildings as examples of how animal-housing problems are solved.

FIG. 406. This Maine boy has made himself a steam-heated hotbed. He fills the tin tank with water, lights a fire under it, and the warm air and steam travel through the pipe to the hotbed.

HOW DOES MAN PROVIDE SHELTER FOR GROWING YOUNG PLANTS? Did you ever see a *hotbed* like the one in Figure 406? These and *cold-frames* are used to protect growing young plants from the cold. They are so built that they allow light from the sun to enter, and they provide a higher temperature than that found outdoors in early spring. For this reason plants can be started early in the spring while the outdoor temperature is too cold for growing plants. Later, when the temperature is warm enough outside, plants that have been started in hotbeds and cold-frames can be transplanted out-of-doors.

Tomatoes, cauliflowers, peppers, cabbages, sweet potatoes, and other vegetables are often started in hotbeds or cold-frames. Plants that mature quickly, such as radishes, lettuce, and spinach, are often grown in hotbeds until they are ready to use. Starting plants as early as possible has two advantages. Vegetables bring higher prices in the early spring; therefore it is desirable to plant them so that they will mature as early as possible. Plants that get an early start can often mature before their insect enemies have developed. This is, as you can see, another reason for the use of cold-frames or hotbeds.

Let us examine a hotbed to see how it is made. A pit

FIG. 407. This hotbed on a Maryland farm contains little tomato plants ready to be taken out and planted.

about two feet deep is dug into the ground and arranged so that water will not stand in it. Then manure from horse stables is put in the pit to a depth of about twenty inches. A layer of soil is placed on top of the manure. A frame, somewhat like a window-frame, is built around the bed. It should be higher on the north side than on the south. Window-sashes with glass in them are hinged to the north side of the frame for a cover (Figure 407). Finally, soil is banked up around the frame on the outside, and the hotbed is ready to plant.

Hotbeds have a higher temperature than the out-of-doors for two reasons. First, the manure in the hotbed decays because of the action of bacteria upon it. A chemical change takes place in the manure, and this change gives out heat. Second, radiant energy from the sun passes through the glass, and the soil absorbs it. You learned about radiant energy in Unit 5. This energy is changed into heat as it is absorbed by the soil, and the glass keeps the heat from getting out.

A cold-frame works much like a hotbed, except that manure is not used. The frame and sashes are placed directly over the soil in which the seeds are to be planted.

FIG. 408. *Greenhouses* work like hotbeds or cold-frames except that artificial heat must be supplied, just as in your school-room. Greenhouses sometimes cover several acres of soil and are used for growing vegetables and flowers for market all year round.

Of course, cold-frames do not keep plants as warm as hotbeds. So they are sometimes used to "harden" very tender plants that are started in hotbeds. After being hardened in the cooler cold-frames, those plants will stand a better chance of surviving the cold when they are put outside.

Self-Testing Exercises

1. Use the scientific principles you have learned in explaining how a hotbed is kept warm.

2. Give reasons why cold-frames are not so warm as hotbeds. Name some uses of cold-frames.

Problems to Solve

1. Make a list of buildings in your community (*a*) that are used to protect growing crops from cold, and (*b*) that are used to store crops.

2. Find in some reference book what plants are started in hotbeds, cold-frames, or greenhouses. Report your findings to the class. Are any of these plants started in such places in your community?

3. Find how field crops and orchards are protected from cold. Examples: *Plants are covered with newspapers. Smudge fires are started in orchards.*

4. With the aid of a book on farm buildings, draw a simple plan of a building for storing plants.

5. Try to find the cost of building a silo. What materials are used for this purpose in your community?

HOW DO FARMERS PROVIDE PROPER LIVING QUARTERS FOR THEIR ANIMALS? Did you ever go into a well-kept dairy barn or chicken house in winter? There was the clean smell of disinfectant, and fresh air was circulating in the building. But the building was not cold. It was warmer than the air outside, and plenty of sunlight came in through the windows. Probably you thought, "No wonder these animals are profitable to the farmer with such a well-kept place to live!"

The problem of providing proper living quarters for animals is much the same as providing storage and housing for crops. Protection from weather, the proper temperature, ventilation, and sanitation are the chief things to consider. Comfortable house temperature for people varies from 65 to 75 degrees Fahrenheit, depending upon the amount of moisture in the air. However, a temperature varying from 55 to 65 degrees is best for most farm animals. They are used to staying out-of-doors much of the time; so higher temperatures would be harmful.

Let us study a dairy barn as an example of how proper housing is provided for animals. The floors should be made of concrete, and each cow should have an individual stall. In some places 400 cubic feet of space or more for each cow is necessary to meet requirements in producing clean milk. Most health requirements call for three square feet of window-glass space for each cow. This is necessary to give the proper amount of sunlight and ventilation. Ventilation during very cold weather is provided in other ways. For example, large ventilators are placed on top of the

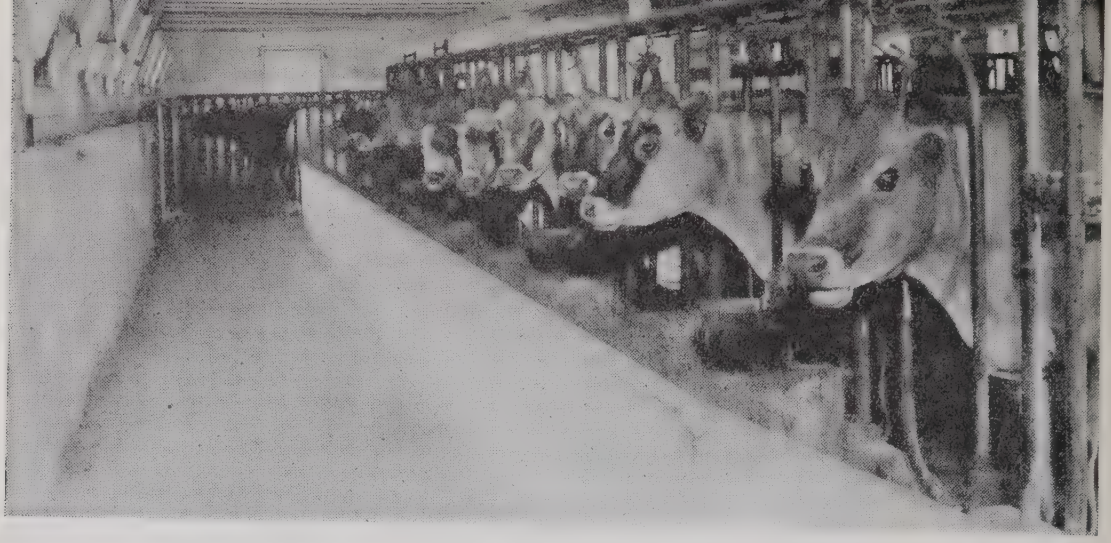


FIG. 409. These Jersey cows on a West Virginia farm have concrete feeding troughs and a well-ventilated, clean barn.

barn, and small openings are made in the walls near the floor. Dampers in these openings regulate the amount of cold air that comes in and the amount of warm air that goes out through the flues.

Watering-troughs should be placed in each stall, or there should be a large, central watering-trough inside the barn for use in cold weather. Cattle do not like to drink very cold water in the winter. So, if they have to drink outside, they will not drink enough water, and the amount of milk they give will be reduced.

Well-placed stalls, gates, and doors help in getting the cattle in and out of the building. Probably you think that all of this is too much trouble, but you must remember that the dairy men are handling food for human beings. Therefore, as much care as possible should be taken in planning proper conditions for the cows. Also, dairy cows are bred for a high rate of milk production rather than for strength, and a dairy cow that is properly cared for is very efficient in her business. So these animals need proper housing and protection if they are to give the best returns for the money the farmer invests.

Poultry-raising is another branch of farming that requires careful planning of buildings. Before you study the needs of chickens, let us learn something about the

FIG. 410. Notice that almost all of one side of this chicken house on a Pennsylvania farm can be opened for sunlight and ventilation.

chickens themselves. Your normal body temperature is about 98.6° Fahrenheit, while the average temperature of a chicken is about 106°. When you are too warm, you perspire to get rid of some of the moisture. Did you ever see a chicken "pant" on a very hot day? Chickens have no sweat glands; so they must give off extra heat through their lungs. You breathe between twelve and fifteen times each minute, but a chicken breathes faster than you do.

Another interesting fact about chickens is that they must have plenty of sunlight. The ultra-violet rays of sunlight help keep their bodies in good condition, and eggs will not hatch unless the hens have had plenty of sunlight. Also, lack of sunshine causes the eggs to have very thin shells, which is a great disadvantage in shipping or incubating them. Since you know these facts about chickens, you can understand why poultry houses must be so carefully planned.

Now let us see how the farmer meets these requirements in planning a house for his chickens. The building should face the south or southeast in order that it may get the most sunlight. It should be built on sandy loam soil, if possible, so that the yard will dry quickly because chickens suffer more from cold when the air is damp. About three square feet of floor space should be allowed for each

grown chicken. The poultry house should be about seven feet high, so that the farmer can move about easily. A higher roof would cause drafts and let the heat rise too high above the chickens. Temperature control depends upon the way the building is constructed, its location, and the kind of ventilation. The joints in the walls should be tightly made, and the roosts should be placed near the ceiling. You remember that warm air rises; so the chickens will be more comfortable if the roosts are high. The roost poles must be large enough so that the chickens can hold on to them easily.

Ventilation is secured by means of windows facing the south. About one square foot of window space to each twelve square feet of floor space is usually considered good, but in warmer localities a part of the entire south wall may be left open. Humidity may be controlled by means of the windows, but, strangely enough, glass is not usually used in them. Glass lets sunlight through, but absorbs most of the ultra-violet rays. Instead of glass, burlap or

FIG. 411. Against the wall and also near the roost, at the right, are the feeding troughs. On the floor, near the center, is a water tank for the chickens. These are White Leghorn chickens on an Indiana farm.

FIG. 412. Did you ever see a hog with a litter of fat, healthy little pigs about her? The pigs frisked about because they were healthy and well-kept. In this picture are some Hampshire hogs on an Indiana farm. Notice the hog houses in the upper left of the picture.

muslin is stretched tightly over the window-sashes. This lets air pass through, helps regulate the humidity of the air inside, but does not absorb ultra-violet rays. On warm days the burlap-covered windows may be opened wide or even removed to let in the full amount of sunlight.

Houses for hogs and their young present another type of problem for the farmer. Of course, the general requirements of protection from weather and of sanitation and ventilation must be met. One way of doing this is to have movable hog houses, each one being just large enough for a sow and her pigs. These houses must be easily moved from place to place. Most individual houses, as they are called, are built on runners so that they can be pulled from place to place as they are needed.

The walls are tight to keep out cold. The roof on the whole front side of the house is hinged at the top so that it can be opened. The entire front wall is a large double door hinged at either side. In this way the ventilation can be controlled, and the house can be opened for cleaning and sunning. Rails, mounted like the bumper of an automobile, are sometimes placed around the inside of

FIG. 413. An individual hog house that is used in some parts of the United States

the house to keep the hog from lying on the pigs. A small door in one end lets the little pigs in and out when the mother must be kept in.

Of course, all of the farm buildings you have studied should be painted to protect them from the weather and to help keep them clean.

You can see now that a farmer must know a great deal to house and feed his animals in the best way. When you think back over all the things he needs to know and all the experiments that are done to discover these facts, you can see why agriculture has become a scientific occupation. Like any other business it requires study, scientific knowledge, and careful planning.

Self-Testing Exercises

1. What is a desirable range of temperature in houses where animals are kept? Is this lower than temperature requirements for people? Explain.

2. What conditions are necessary to keep dairy cows efficient milk producers?

3. List the facts about chickens that should be considered in planning a poultry house. Check with the text to see if you were correct.

4. What are some of the requirements of houses for hogs, other than general requirements for any kind of animal?

Problems to Solve

1. Find what kinds of dairy cattle, chickens, horses, hogs, and other farm animals are raised in your community. Collect pictures of these kinds of animals, if possible, and make a scrap book giving the good and the bad points about each kind of animal.

2. How do the problems of housing crops differ from those of housing farm animals? How are they alike?

LOOKING BACK TO UNIT 11

1. Write a two-page summary of the most important ideas that you have gained from studying this unit. Try to show how science has helped farmers solve their problems intelligently.

2. Make a list of topics in this unit that you would like to learn more about.

3. Show that you know the meanings of the following words:

saturated	*irrigation*	*soil analysis*
dry farming	*fertility*	*commercial fertilizer*
crop rotation	*veterinarian*	*predaceous insects*
tuberculin test	*roughage*	*nutritive ratio*
capillary action	*pest*	*virus*

ADDITIONAL EXERCISES

1. Make as long a list as you can of the advantages of crop rotation in farming.

2. Make a list of all the different reasons for cultivating the soil.

3. Draw a plan of a model farm, showing the location of buildings, fences, trees, roads, fields, and pastures. Make the

drawing on very large paper and use a scale to show sizes—1 inch equals 100 feet, for example. Use references if necessary.

4. Below is a list of some of the most common weeds in the United States. Which of these are pests in your locality? Bring specimens to school and press and mount them for study.

Bermuda grass	dandelion	pigweed	Canada thistle
hedge hindweed	jimson weed	ragweed	common thistle
broom sedge	Johnson grass	sandbur	wild carrot
cheat or chess	prickly lettuce	smartweed	wild oats
cockle-bur	wild mustard	sow-thistle	quack grass

5. Make a list of reasons why you think certain animals or plants were winners at fairs you have visited.

6. Write to the United States Department of Agriculture, Washington, D. C., for a list of Farmers' Bulletins. Select from this list any bulletins related to the topics on which you wanted more information for the preceding exercises. Try to get these bulletins for your school library.

7. Try to raise a vegetable garden or other crop or to care for some animal during your summer vacation. Use the principles you have learned in this chapter in caring for it.

READINGS IN SCIENCE

THIS part of the book is to help you find interesting science reading outside your textbook. The *General Books* named below are books that have parts on a great many different scientific topics. Usually you can find what you want to read by looking for a topic or word in its alphabetical place or in the index.

On page 548 there is a list of magazines that may interest you. Following the magazines are the *Books on Special Topics*. These books are of many different kinds. Some of them are interesting to read all the way through. A few are on topics in which you may be interested but that are not discussed in this book. Some of these books will be most useful when you want to find out more about some special topic for your own satisfaction and for reports to your class. Others give directions for making things and doing experiments.

Probably you cannot find all these books or magazines in your school or public library, but almost every library will have some of those named or others very much like them. Ask your librarian how to look for them on the science shelf or in the card catalog of the library.

I. GENERAL BOOKS

Book of Knowledge (20 volumes). Grolier Society, 1931.
Book of Popular Science (16 volumes). Grolier Society, 1931.
Boy Scouts of America. The Official Scout Handbook for Boys, 1935.
Compton's Pictured Encyclopedia (15 volumes). F. E. Compton and Co., 1937.
Girl Scouts of America. The Official Scout Handbook for Girls, 1933.
World Book Encyclopedia (13 volumes). W. F. Quarrie and Co., 1934.

II. MAGAZINES

Current Science, American Education Press, Inc., 400 S. Front St., Columbus, Ohio.
Junior Natural History, American Museum of Natural History, Central Park West at 79th St., New York, N. Y.
Junior Scholastic, Scholastic Corp., Chamber of Commerce Building, Pittsburgh, Pa.
National Geographic Magazine, National Geographic Society, Washington, D. C.
Nature Magazine, American Nature Association, 1214 Sixteenth St., N.W., Washington, D. C.
Popular Mechanics, Popular Mechanics Co., 200 E. Ontario St., Chicago, Ill.
Popular Science Monthly, Popular Science Publishing Co., 381 Fourth Ave., New York, N. Y.
Science Digest, Science Digest, Inc., 631 St. Clair St., Chicago, Ill.
Science News Letter, Science Service, Inc., 2101 Constitution Ave., Washington, D. C.
Scientific American, Munn & Co., Inc., 24 W. 40th St., New York, N. Y.

III. BOOKS ON SPECIAL TOPICS

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Washburne, Carleton and Heluiz. *The Story of Earth and Sky* (pages 3-12, 93-262). Appleton-Century, 1935.
White, W. B. *Seeing Stars.* Harter, 1935.

Unit 2: How Is the Force of Gravity Useful to Us?

Beebe, C. W. *Exploring with Beebe.* Putnam, 1932.
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Bolton, S. K. *Famous Men of Science* (pages 10-46). Crowell, 1926.
Cottler, Joseph, and Jaffe, Haym. *Heroes of Civilization* (pages 98-107, 117-127). Little, 1931.
Cottler, Joseph, and Jaffe, Haym. *Heroes of Science* (pages 12-21, 31-41). Little, 1932.
Darrow, F. L. *Masters of Science and Invention* (pages 3-17, 327-335). Harcourt, 1923.
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Hylander, C. J. *American Scientists* (pages 171-173). Macmillan, 1935.
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Lansing, M. F. *Great Moments in Freedom* (pages 145-152). Doubleday, 1930.
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Pollak, Janet. *This Physical World* (pages 11-33). Follett, 1930.
Rowbotham, F. J. *Story-Lives of Great Scientists* (pages 21-44, 65-80). Gardner, 1918.
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Williams-Ellis, Amabel. *Men Who Found Out, Stories of Great Scientific Discoverers* (pages 14-15, 25-60). Coward-McCann, 1930.

Unit 3: How Does the Earth's Surface Change?

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Fabre, Jean-Henri. *This Earth of Ours* (Chapters VIII, IX, X, XI, XIII, XIV, XVIII, XIX, XX, XXI). Appleton-Century, 1923.

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SCIENCE WORDS

HERE is a list of the important science words in this book, with the pronunciation and the meaning of each one. The marked letters in parentheses are sounded according to the letters in the following list of sample words. The accented syllable is marked ′. This lighter mark ′ shows a lighter accent.

a at, can	ē be, equal	o̤ actor, second
ā came, face	ė her, certain	oi oil, point
ä far, father	e̤ towel, prudent	ou out, found
â all, ball	i it, pin	s̤ nausea
ȧ ask	ī line, mine	t̤ picture
ã care, dare	o on, not	ŦH then, they
a̤ alone, company	ō more, open	u up, but
ä̤ beggar, opera	ö to, move	ū use, pure
e end, bend	ô off, song	u̇ put, full
		ṳ̄ nature

A single dot under ā, ē, ō, ö, or ū means that the sound is a little shorter and lighter, as in cot′tā̤ge, rē̤-dūce′, gas′ō̤-line, in′tö̤, ṳ̄-nī′ted.

ad he sion (ad-hē′zho̤n): sticking together of two different substances.

ad o les cent (ad-ō̤-les′e̤nt): growing up to manhood or womanhood; person from about 13 to 18.

air sac: one of the tiny air spaces of a lung. Each air sac is at the end of a tiny branch of a bronchial tube.

al i men ta ry (al-i-men′ta̤-ri) **canal:** the parts of the body through which the food passes while it is being digested.

al tim e ter (al-tim′e-tėr): an instrument that measures changes in the height above sea-level.

an e mom e ter (an-ē̤-mom′e-tėr): an instrument that shows the speed of the wind in miles per hour.

an ther (an′thėr): the part of the stamen that bears the pollen.

an ti bod ies (an′ti-bod-iz): chemicals produced in the blood of an animal or man that help overcome germs or their poisons.

an ti sep tic (an-ti-sep′tik): a substance that kills or prevents the growth of germs.

an ti tox in (an-ti-tok′sin): a substance formed in the body that acts against the poisons produced by germs; a substance manufactured by an animal having a certain disease and that can be injected into the body of another animal to assist in the neutralization of poisons given off by germs.

a nus (ā′nus): the opening at the end of the alimentary canal, through which waste material and undigested food pass.

a or ta (ā-ôr′tä): the main artery that carries the blood from the left side of the heart to all parts of the body except the lungs.

Ar chi me des' Principle: (är-ki-mē′dēz) An object placed in a fluid is buoyed up (pushed upward) by a force equal to the weight of the fluid that it displaces.

ar te ry (är′tẹ-ri): a blood vessel that carries blood from the heart.

as trol ogy (as-trol′ọ-ji): a false science that claims to determine the influence of the stars and planets on persons, events, etc.; studying the stars to foretell what will happen.

as tron o my (as-tron′ọ-mi): the science of the sun, moon, planets, stars, etc.

at mo sphere (at′mọs-fēr): the air that surrounds the earth.

at mo spher ic pres sure (at-mọs-fer′ik presh′ūr): the force with which the atmosphere presses on things. To scientists it is the force on a unit area, such as one square inch. Atmospheric pressure at sea-level is about 15 pounds per square inch.

ba cil lus, plural ba cil li (ba-sil′us, ba-sil′ī): any of the cylinder-shaped bacteria.

bac te ri ol o gist (bak-tē-ri-ol′ọ-jist): one who studies bacteria.

bar o graph (bar′ọ-gråf): a recording barometer that makes a graph of air-pressure.

ba rom e ter (bạ-rom′e-tėr): an instrument for measuring the pressure of the atmosphere.

bath y sphere (bath′i-sfēr): a heavy steel sphere from which deep-sea observations are made.

bi ceps (bī′seps): large muscle in front part of upper arm.

bi en ni al (bī-en′i-ạl): a plant that requires two growing seasons to complete its life cycle.

bile (bīl): a bitter yellowish liquid secreted by the liver. Bile aids digestion.

bot a nist (bot′ạ-nist): a scientist who studies plants and plant life.

bron chi al (brong′ki-ạl) **tube:** the two large, main branches of the windpipe and the small branches of each of these.

cam bi um (kam′bi-um): a layer of delicate growing cells between the bark and wood of trees and shrubs, that divide to form new wood and bark.

cap il la ry (kap′i-lā-ri): a tiny blood tube that connects an artery with a vein.

car ti lage (kär′ti-lāj): gristle; a firm, elastic, flexible substance forming parts of a skeleton.
cen trif u gal (sen-trif′ū-gal) **force:** the force that makes whirling things fly away from the center.
chi tin (kī′tin): a hard material in the outer covering of animals such as insects, crabs, lobsters, etc.
chol e ra (kol′ẹ-rä): a serious disease of the digestive organs.
cil i a (sil′i-ä): microscopic living, moving hairs, such as those that cover the linings of the breathing passages.
cir rus (sir′us): tufted, thread-like, or feather-like clouds.
clin ic (klin′ik): a place for medical instruction and treatment.
coc cus, plural **coc ci** (kok′us, kok′sī): a ball-shaped bacterium.
co coon (kọ-kön′): a silky case or shell made by worms and caterpillars to live in while they are turning into moths or butterflies.
con duc tion (kọn-duk′shọn): the movement of heat from molecule to molecule through a material.
con glom er ate (kọn-glom′ẹ-rāt): a rock made of pieces of gravel held together by crystals of dissolved minerals and great pressure.
co he sion (kō-hē′zhụn): the sticking together of the molecules of a given kind of substance.
con nec tive tis sue (kọ-nek′tiv tish′ọ̈): a substance in the bodies of men and animals that connects, supports, or surrounds other tissues and organs.
con stel la tion (kon-ste-lā′shọn): a group of stars.
con vec tion (kọn-vek′shọn): the movement of heat in a liquid or gas by means of currents from hotter to colder bodies.
cor pus cle (kor-pus-l): a cell, either red or white, in the blood. The corpuscles are the solid part of the blood.
cot y le don (kot-i-lē′dọn): one of the first leaves of the embryo plant in a seed. In corn and bean seeds the cotyledons are thickened with a store of food for the young plant.
cross-pol li na tion (krôs′pol-i-nā′shọn): carrying pollen from the flower of one plant to the stigma of a flower of another plant of the same kind.
cul ture (kul′ṭụr): some jelly or liquid in which a certain kind of bacteria (or other organism) is growing for some purpose.
cu mu lus (kū′mụ-lus): a dome-shaped cloud with a flat base.

den si ty (den′si-ti): the amount of material in a unit volume of a substance, such as the number of pounds of wood in a cubic foot.
den tine (den′tin): bony material beneath the enamel of a tooth.
dew point: the temperature of the air at which dew begins to form.
di ag no sis (dī-ag-nō′sis): deciding what disease a person has by studying him; determining the nature of any condition by an examination of it and its symptoms.
di a phragm (dī′ạ-fram): a partition of muscles and tendons separating the cavity of the chest from the cavity of the abdomen.

di as tro phism (dī-as′trō-fizm): the rising and falling of the earth's surface and other changes in the positions of rocks.
di cot y le don ous (dī′kot-i-lē′dọn-us) **plant:** a plant with an embryo that has two cotyledons.
dif fu sion (di-fū′zhọn): the moving of a material from one place to another by the bouncing of the separate molecules.
di gest (di-jest′ or dī-jest′): change food in the stomach and intestines so that it will dissolve and the body can use it.
dis lo ca tion (dis-lō-kā′shọn): being put out of joint.
dis place ment (dis-plās′mẹnt): the weight of water (or other liquid) pushed aside by a ship or other floating body. It is equal to the weight of the floating body.
duct: a tube or canal for carrying liquid.

e clipse (ē-klips′): passing from sight because light is cut off.
em bry o (em′bri-ō): an animal or plant in the earlier stages of its development, or before birth or germination.
en do crine (en′dō-krīn or -krin): pertaining to certain glands in the body that put their secretions into the blood.
en er gy (en′ėr-ji): power to make matter move or change.
en to mol o gist (en-tō-mol′ō-jist): a scientist who studies insects.
ep i dem ic (ep-i-dem′ik): the rapid spreading of a disease so that many people have it at once.
ep i glot tis (ep-i-glot′is): a flap that covers the top of the windpipe during swallowing, so that food does not get into the windpipe.
e ro sion (ē-rō′zhọn): an eating away or a wearing away. The surface of the earth is eroded by the action of water, ice, and wind.
e soph a gus (ē-sof′ạ-gus): the passage for food from the mouth to the stomach; the gullet.

fault: a break in rocks that allows them to move past each other.
feld spar (feld′spär): a dull, somewhat transparent mineral found in granite.
fer ti li za tion (fėr′ti-li-zā′shọn): the uniting of the nuclei of male and female reproductive cells.
fil a ment (fil′ạ-mẹnt): very fine thread or thread-like structure; in a flower the part of the stamen that supports the anther.
fis sion (fish′ọn): splitting into parts; reproduction of a one-celled plant or animal by division of the cell.
flu id (flö′id): any substance, either gas or liquid, that will flow.
force: a push or pull that tends to set a body in motion or to stop a body that is already moving, or to change the direction in which a body is moving.
fos sil (fos′il): the hardened remains of an animal or a plant.
fric tion (frik′shọn): rubbing of one thing against another; resistance to motion of surfaces that touch each other.

ful crum (ful′krum): the support on which a lever turns in moving something.
fu mi ga tion (fū-mi-gā′shọn): exposing to smoke or fumes, as in disinfecting.

gal ax y (gal′ạk-si): an arrangement of countless stars in a group.
gall blad der (gâl′blad′ėr): the sac that receives the gall or bile from the liver.
gas tric (gas′trik) **juice:** the digestive liquid produced by glands in the wall of the stomach.
ge ol ogist (jē-ol′ọ̄-jist): a scientist who studies the structure and changes of the earth.
germ (jėrm): a one-celled, microscopic plant or animal that causes disease, as the germ of scarlet fever.
ger mi cide (jėr′mi-sīd): something that kills germs.
ger mi na tion (jėr-mi-nā′shọn): the starting of growth in a pollen grain or seed.
gland: a group of cells that makes and gives out some substance.
glot tis (glot′is): the opening at the upper end of the windpipe.

gram: a unit of weight in the metric system; about $\frac{1}{29}$ of an ounce.
grav i ta tion (grav-i-tā′shọn): the fact that the earth pulls all things toward it and that the sun, moon, stars, and planets do the same; the force or pull that makes bodies in the universe tend to move toward one another.
grav i ty (grav′i-ti): the force that pulls things toward the earth.
gris tle (gris′l): hard elastic tissue; cartilage.

hem o glo bin (hem-ọ̄-glō′bin): the red substance in the blood.
hu mid i ty (hū-mid′i-ti): the amount of moisture in the air.
hu mus (hū′mus): the part of soil that is made from decayed and decaying plant or animal material.
hy drom e ter (hī-drom′e-tėr): an instrument for finding the density of a liquid.
hy dro sphere (hī′drọ̄-sfēr): the name given to all the water on the earth taken together.
hy poth e sis (hī-poth′e-sis or hi-poth′e-sis): the best solution that can be thought of for a problem at any given time; a statement that cannot be proved to be true, but that offers the best explanation for the known facts.

ig ne ous (ig′nẹ̄-us) **rock:** rock that has melted and hardened.
im mune (i-mūn′): not susceptible. A person who is immune to a contagious disease does not take it even though he gets some of the germs in his body.
im per vi ous (im-pėr′vi-us): not letting a thing pass through.
in cu bate (in′kụ̄-bāt): sit on eggs to hatch them; warm eggs or bacteria by artificial heat to cause them to develop.

incubation (in-kụ̄-bā′shọn) **period:** the time between infection and the appearance of the symptoms of a disease.
inertia (in-ėr′shiạ̈): tendency of all objects to stay still if still, or, if moving, to go on moving in the same direction, unless acted on by some outside force.
infection (in-fek′shọn): taking or getting germs into the body.
infectious disease (in-fek′shus di-zēz′): a disease caused by growth of germs in the body. Many infectious diseases can be spread from one person to another.
insulator (in′sụ̄-lā-tọr): material that prevents the passage of electricity or heat; non-conductor.
intestine (in-tes′tin): a part of the alimentary canal.
isobar (ī′sọ̄-bär): a line on a weather map connecting places having the same atmospheric pressure (barometer reading).
isolate (is′ọ̄-lāt or ī′sọ̄-lāt): place apart.
isotherm (ī′sọ̄-thėrm): a line connecting places that have the same temperature.

kidney (kid′ni): one of the pair of organs that separate waste matter and water from the blood and pass it off through the bladder in liquid form.
kilogram (kil′ọ̄-gram): a standard of weight in the metric system equal to 1000 grams or about 2.2 pounds.
kinetic (ki-net′ik or kī-net′ik) **energy:** the form of energy that all moving objects have.

lacteal (lak′tē-ạl): one of the tiny tubes that takes a milky fluid containing digested fats from the small intestine to be mixed with the blood.
larva, plural **larvae** (lär′vạ̈, lär′vē): the grub or caterpillar of an insect from the time of leaving the egg until it becomes a pupa.
larynx (lar′ingks): the upper end of the windpipe, where the vocal chords are.
latitude (lat′i-tūd): distance north or south of the equator, measured in degrees.
lava (lä′vạ̈): melted rock that flows from volcanoes or through great cracks in the earth.
lens (lenz): glass or glass-like material so made as to bring closer together or send wider apart the rays of light passing through it.
life cycle (sī′kl): all the stages in the life of an organism from a fertilized egg to an adult.
ligament (lig′ạ-mẹnt): a band of strong tissue that connects bones or holds parts of the body in place.
light year: the distance that light travels in one year.
lithosphere (lith′ọ̄-sfēr): the main solid part of the earth, composed of rocks and soil.
liver (liv′ėr): the large reddish-brown organ in people and animals that makes bile and aids in the digestion of food.

loam (lōm): rich soil made up of clay, sand, and decayed plant materials in approximately equal parts.
lon gi tude (lon′ji-tūd): distance east or west of the prime meridian at Greenwich, England, measured in degrees.
lu mi nous (lū′mi-nus): bright; shining by its own light.

mam mal (mam′ạl): an animal that suckles its young.
mechanical energy: energy possessed by moving bodies or by bodies because of their position.
me rid i an (mẹ-rid′i-ạn): a circle passing through any place on the earth's surface and through the north and south poles.
met a mor pho sis (met-ạ-môr′fō-sis): a change of form.
me te or (mē′tẹ-ọr): a small body of material that falls with great speed from space into the earth's atmosphere.
me te or ite (mē′tẹ-ọr-īt): a mass of stone or metal that has reached the earth from outer space.
me te or o graph (mē′tẹ-ọ-rọ-gråf): an instrument used for recording the temperature, pressure, and humidity of the air.
met ric (met′rik) **system:** the system of measurement that is based on the meter as the standard unit of length and on the kilogram as the unit of weight.
mi ca (mī′kạ̈): a mineral that splits into thin, partly transparent layers.
mol e cule (mol′e-kūl or mō′le-kūl): the smallest particle into which a substance can be divided without chemical change.
molt (mōlt): shed the feathers, skin, etc., before a new growth.
mon o cot y le don ous (mon′ọ-kot-i-lē′dọn-us) **plant:** a plant that has an embryo with one cotyledon.
moon: a body that revolves around a planet.
mo raine (mọ-rān′): a pile of material dropped at the end or the sides of a glacier as it melts.
mu cous mem brane (mū′kus mem′brān): the lining of the nose, throat, and other cavities of the body.
mu cus (mū′kus): a slimy substance that moistens the linings of the body.
my ce li um (mī-sē′li-um): the mass of thread-like material forming part of a fungus, like bread mold.

na sal (nā′zạl) **passage:** one of the openings leading from the nostrils to the throat.
neb u la, plural **neb u lae** (neb′ụ-lạ̈, neb′ụ-lē): an irregular-shaped glowing mass of gas or of other galaxies of stars than our own.
node (nōd): a place on the stem where a leaf or bud grows; a joint in a stem.
non-con duc tor (non-kọn-duk′tọr): a material that conducts heat or electricity very slowly or not at all.
nu tri tive ra tio (nū′tri-tiv rā′shiō or rā′shō): the proportion be-

tween the digestible proteins and combined carbohydrates and fats together in a food or diet.

nymph (nimf): a young insect that has the general form of, yet is different from, the adult, as, a grasshopper in its wingless stage.

objective (ọb-jek′tiv): a large lens that forms the picture of what is to be seen in a telescope.

orbit (ôr′bit): the path of the earth, or any planet, about the sun; the path of any heavenly body about another heavenly body.

organic (ôr-gan′ik): of the bodily organs; affecting the structure of an organ, as organic disease.

organic material: a material that was once part of a living thing.

organism (ôr′gạn-izm): an individual plant or animal.

ovary (ō′vạ-ri): 1. the organ of a female in which eggs are produced. 2. the part of a plant enclosing the young seeds.

oviduct (ō′vi-dukt): the canal through which an egg passes from the ovary of an animal.

oviparous (ọ̄-vip′ạ-rus): egg-laying.

ovule (ō′vūl): the part of a plant that develops into a seed.

pancreas (pan′krē̤-as or pang′krē̤-as): a gland near the stomach that helps digestion.

pancreatic (pan-krē̤-at′ik or pang-krē̤-at′ik) **juice:** the fluid that the pancreas secretes.

pasteurization (pas′tėr-i-zā′shọn): killing germs in milk by heating it to 144° F. for 30 minutes.

pelvis (pel′vis): the basin-shaped bony structure between the hips.

pepsin (pep′sin): a substance in the gastric juice of the stomach that digests meats, eggs, cheese, and similar foods.

perennial (pẹ-ren′i-ạl): a plant living more than two years.

pharynx (far′ingks): the cavity at the back of the mouth where the passages to the nose, lungs, and stomach begin.

phase (fāz): the apparent shape of the moon or of a planet at a given time. The new moon, first quarter, full moon, and last quarter are four phases of the moon.

pistil (pis′til): the seed-bearing part of a flower.

planet (plan′et): a heavenly body that moves around the sun.

planetesimal (plan-e-tes′i-mạl): one of the small bodies believed to have come from the sun and united with other similar bodies to form the planets and moons of our solar system.

planetoid (plan′e-toid): a small planet that revolves around the sun.

plastic (plas′tik): putty-like; easily molded or shaped.

Pleurococcus (plö-rọ̄-kok′us): a one-celled green plant that grows as a green stain on the north side of trees and in damp places.

pneumatic (nū-mat′ik): worked by air-pressure.

pollen (pol′ẹn) **tube:** the tube that grows out of the pollen grain down the style to the ovary in a flower.

pol li na tion (pol-i-nā′shọn): carrying pollen grains from the stamen to the pistil.
po ten tial (pō-ten′shạl) **energy:** stored-up energy possessed by materials because of their chemical composition, their position, or their condition.
pre da ceous (prē-dā′shus) **insect:** an insect used to fight other insects that damage crops.
prim ing (prīm′ing): preparing by putting something in or on. A pump is primed by pouring water into it to remove the air so that the pump will work.
prism (prizm): a triangular piece of glass used to spread out a ray of light into a band of rainbow colors.
prop er ty (prop′ėr-ti): a characteristic of an organism or a substance that helps to tell what it is.
pu pa, plural **pu pae** (pū′pạ̈, pū′pē): a stage in the life of an insect when it is in a case. It comes between the larva and the winged adult stage.
pus: whitish or yellowish, watery material that collects in sores.

quartz (kwârts): a clear, glass-like, and hard mineral composed of the elements silicon and oxygen. Sand is mostly quartz.

ra di ant (rā′di-ạnt) **energy:** energy in the form of visible or invisible rays from some heated source.
radiant heat: invisible radiant energy of a kind that changes to heat when it strikes something and is absorbed.
ra di ate (rā′di-āt): give out rays of light, radiant heat, etc.
ra di a tion (rā-di-ā′shọn): giving out light, radiant heat, etc.
ra di o ac tive (rā′di-ọ̄-ak′tiv): used to describe an element like radium that gives out heat energy all the time as it changes into other substances.
ra tion (rā′shọn or rash′on): a fixed allowance of food.
re cep ta cle (rē-sep′tạ-kl): the enlarged tip of a stem that holds the parts of a flower.
re flect (rē-flekt′): throw back (light, heat, sound, etc.).
re fract ing (rē-frakt′ing): bending (a ray of light, etc.) from a straight course.
re frig er a tion (rē-frij-ẹ-rā′shọn): act or process of cooling or keeping cool.
re gen er a tion (rē-jen-ẹ-rā′shọn): growing again; bringing or coming into new existence.
re pro duc tion (rē-prọ̄-duk′shọn): the process by which new living things are created.
res pi ra tion (res-pi-rā′shọn): 1. the chemical change in cells in which oxygen is used to secure energy from foods and carbon dioxide is thrown off. 2. the taking of oxygen into the body and giving out of carbon dioxide.

respiratory (rē-spīr′ə-tō-ri or res′pi-rə-tō-ri) **system:** the breathing system.
rhizome (rī′zōm): an underground stem.
rotor (rō′tər): the rotating or turning part of a machine.
roughage (ruf-āj): the coarser parts or kinds of food.

saliva (sə-lī′və): the liquid produced by glands in the mouth that helps dissolve food.
salivary (sal′i-vā-ri) **gland:** a group of cells that produce saliva.
satellite (sat′ə-līt): a moon, or any body that revolves around a planet.
saturate (saṭ′ū-rāt): soak thoroughly; fill full.
saturated (saṭ′ū-rāt-ed) **air:** air containing all the water vapor that it can hold.
secrete (sē-krēt′): make; prepare; produce.
sediment (sed′i-mənt): material carried by liquid and which gradually settles to the bottom.
sedimentary (sed-i-men′tə-ri) **rock:** rock layer formed from sediment in water.
self-pollination (self-pol-i-nā′shən): carrying pollen from a stamen to the stigma of the same flower.
sepal (sē′pəl): one of the leaf-like divisions of the calyx, or outer covering of a flower.
shale (shāl): sedimentary rock made of hardened clay, etc., that splits readily into thin layers.
sinus (sī′nus): one of the small pockets in the bones of the head.
skeletal (skel′ə-təl): having to do with the skeleton.
slate: a bluish-gray rock that splits easily into thin smooth layers.
solar (sō′lər) **system:** the sun and all the planets that revolve around it.
spectrograph (spek′trō-gråf): an instrument for taking a picture of the band of colors formed when a ray of light from any source is broken up.
spectroscope (spek′trō-skōp): an instrument for obtaining and examining the band of colors formed when a ray of light from any source is broken up.
spectrum (spek′trum): the band of colors formed when a ray of light is broken up by being passed through a prism or by some other means.
sperm (spėrm): one of the male germ cells of plants and animals.
spinal (spī′nəl) **cord:** a cord of nerve tissue inside the backbone.
spirillum, plural **spirilla** (spī-ril′um, spī-ril′ə): a spiral-shaped bacterium.
spontaneous generation (jen-ə-rā′shən): the theory that living things are produced from non-living matter.
spore (spōr): a single cell, usually with a heavy covering, that can grow into a new plant.

sta lac tite (stą-lak′tīt or stal′ak-tīt): a formation of lime material, shaped like an icicle, hanging from the roof of a cave.
sta lag mite (stą-lag′mīt or stal′ag-mīt): a formation of lime material, shaped like a cone, built up on the floor of a cave.
sta men (stā′men): the part of a flower that bears the anther containing the pollen.
ster il i za tion (ster′il-i-zā′shọn): killing germs on objects by heating them in boiling water, live steam, or dipping them in chemicals.
ster il ize (ster′il-īz): make free from living germs.
stig ma (stig′mä): the sticky tip of the pistil of a plant. It receives the pollen.
sto lon (stō′lon): a runner from a plant that lies along the ground and develops new plants from its nodes.
stra ta (strā′tä): layers of earth or rock.
strat i fied (strat′i-fīd) **rock:** rock arranged in layers.
stra to sphere (strā′tọ-sfēr): thin air about 7 miles and more above the earth.
stra tus (strā′tus): a layer-like cloud of low altitude.
strep to coc cus (strep-tọ-kok′us): ball-shaped bacteria. Often they stay attached in the form of a chain.
stri ae (strī′ē), singular **stri a** (strī′ä): scratches and grooves left on the surfaces of rocks over which glaciers have passed.
style: the stem-like part of the pistil between stigma and ovary.
sub soil (sub′soil): the layer of lighter-colored earth that lies just under the surface soil.
sun time: time in which noon is the moment when the sun is directly overhead.
system: a set of organs in the body, all helping in one kind of work, as the circulatory system.

ten don (ten′dọn): a tough strong band or cord that joins a muscle to a bone.
ther mo graph (thėr′mọ-gråf): an instrument that makes a record of the temperature for a day, a week, or longer.
tho rax (thō′raks): the cavity of the chest.
tox in (tok′sin): poison produced in animals or plants by germs.
tox in-an ti tox in (tok′sin-an-ti-tok′sin): a mixture of toxin and antitoxin that gives the body active immunity. While the toxin is causing the blood to make germ-fighting chemicals, the antitoxin prevents the toxin from harming the body.
tra che a (trā′kẹ-ä): the "windpipe," the passage that conducts air from the throat to and from the lungs.
trans form (trans-fôrm′): change in condition, as from potential to kinetic energy.
tri chi na (tri-kī′nä): a small worm that sometimes lives in the muscles of men, hogs, and other animals, causing disease.
trich i no sis (trik′i-nō′sis): a disease caused by the trichina.

tuberculin (tū-bėr′kū-lin) **test:** a test to find whether an animal has tuberculosis.
tuberculosis (tū-bėr-kū-lō′sis): a disease affecting various tissues of the body, but most often the lungs.

urea (ū′rē-ą or ū-rē′ą): nitrogen wastes from the body in the form of a white chemical compound found in urine.
ureter (ū-rē′tėr): a tube through which urine goes from the kidney to the bladder.
urethra (ū-rē′thrą): the tube from the bladder through which urine is discharged from the body.
urinary bladder (ū′ri-nā-ri blad′ėr): the soft, thin bag-like organ which receives urine from the kidneys.
urine (ū′rin): the fluid containing waste matter taken from the blood by the kidneys, which goes to the bladder and is then discharged from the body.

vaccine (vak′sin or vak′sēn): a substance injected under the skin to produce a mild form of a disease, used for the protection of people against the real disease.
vacuum (vak′ū-um): empty place from which everything, including air, has been removed.
vein: one of the blood vessels or tubes that carries blood to the heart from all parts of the body.
vertebra, plural **vertebrae** (vėr′tę-brą, vėr′tę-brē): one of the bones of the backbone.
vertebrate (vėr′tę-brāt): having a backbone; an animal with a backbone.
veterinarian (vet′ę-ri-nā′ri-ąn): animal doctor.
villus, plural **villi** (vil′us, vil′ī): one of the thousands of tiny finger-like projections in the small intestine of the body that help to absorb food.
virus (vī′rus): a liquid or other material that will cause an infectious disease if put into the blood. Usually virus means a material in which no germs can be found, yet which will cause a disease like smallpox, measles, etc.
viviparous (vī-vip′ą-rus): bringing forth young alive rather than by the laying of eggs.
volcanic (vol-kan′ik) **ash:** dry ash-like material formed when the air cools bits of melted rock that burst out of an erupting volcano.
von Guericke, Otto (fǫn gā′ri-kė, ot′ō): a German physicist (1602-1686).

weathering: the process of softening and breaking up rocks as a result of the chemical action of air and water on them.
work: moving something by pushing or pulling it. The amount of work done depends on how hard one pushes or pulls and on how far the object is moved.

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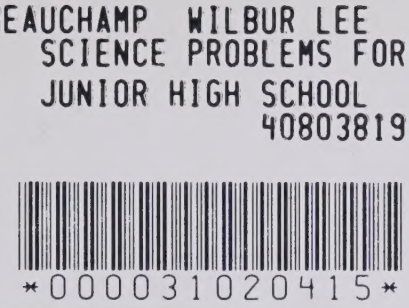

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